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Rathbun Lake Watershed assessment and water quality implications of switchgrass biomass production

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Rathbun Lake Watershed Assessment and Water Quality Implications of Switchgrass Biomass Production

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has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy

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Abstract

Rathbun Lake is a 4,455-hectare multipurpose water resource in southern Iowa. Its long-term ability to meet all of its designated uses is threatened by excessive siltation, nutrient enrichment, and pesticide runoff. A comprehensive watershed assessment is necessary to identify the sources and locations of these pollutants. The Soil and Water Assessment Tool (SWAT) was selected for this study. The two objectives were to: (1.) rank the 61 subbasins of Rathbun Lake Watershed as to their relative environmental impact on runoff water quality, and (2.) evaluate the runoff water quality implications of using switchgrass for biomass production.

The ArcView® SWAT interface version 1.601was selected for this study. The ArcView® geographic information system (GIS) was desired to be used to demonstrate the utility of this technology and to automate the data entry workload. The digital elevation model (DEM), land use/land cover, and soils GIS coverages were obtained from government agencies. Weather, crop, fertilizer, and pesticide database information was supplied by the SWAT model or were obtained through literature review, subject matter experts, or existing site-specific databases. Management practice schedules were obtained by interviewing watershed farmers and local agency personnel familiar with farming practices in the watershed. Land use distribution by subbasin was analyzed to obtain the maximum acreage of forest with the minimum number of hydrologic response units (HRUs). The soils threshold for the HRUs was selected based upon experience. Using average annual stream discharge, the model was calibrated for 1966-1986 and validated for 1987-1999. The model ranked the 61 subbasins on their relative production of sediment yield and nitrogen, phosphorus, and atrazine loading. In general, subbasins that ranked the highest had a high percent of row cropland and 4-5% average subbasin slope. Growing switchgrass for biomass was shown to have several environmental benefits. A switchgrass scenario defined as growing switchgrass on approximately 38% of the row crop area, reduced sediment yield and nutrient loading more than a third compared to the baseline (current conditions) scenario. The quantity of sediment-bound atrazine delivered to Rathbun Lake is predicted to be reduced 84%.

Introduction

Rathbun Lake Watershed is located in southern Iowa (Figure 1). Rathbun Lake is on the Chariton River and was formed when Rathbun Dam became operational in November 1969. Rathbun Lake watershed has 1,422 square kilometers (km^2) (549 mi^2) drainage area. The lake has 4,455 hectares (ha) (11,000 acres) surface water at normal pool elevation and contains an estimated 2.53×10^8 cubic meters (m^3) (205,000 acre-feet) of water at normal pool elevation (U. S. Army Corps of Engineers, 2001). However, Rathbun Lake has been filling with sediment three times faster than anticipated (Southern Iowa Development and Conservation Authority, unpublished data, 1999). Excessive levels of nutrients and pesticides posing threats to human health, wildlife and water quality have been measured in the lake water as well as in the major tributaries contributing to the lake. These observations have convinced local watershed planners and water users to develop a comprehensive watershed management plan to protect the water quality of Rathbun Lake. But to prepare a comprehensive management plan, a comprehensive watershed assessment is needed in order to target scarce resources efficiently and with maximum effect.

The purpose of this study is to help complete an assessment on the current conditions of Rathbun Lake watershed using a modeling approach. A second objective is to study the water quality effects of growing switchgrass for biomass production. Growing switchgrass is being pursued as an alternative crop to growing corn and soybeans on erosive soils in the area, particularly within the Rathbun Lake watershed. This study will help determine if switchgrass biomass production results in less environmental degradation than corn and soybean production.

This project was completed making assumptions and generalizations of current land use and farming practices in the watershed. However, to fully appreciate the study area and the environmental problems being faced, an understanding of the area's physical resources and history is necessary. A brief description of the major physical resources and a brief history of the study area are provided.

Physical Resources

<u>Geology.</u> The bedrock underlying the Chariton River Valley is Pennsylvanian-age sandstone, limestone, and shale. Layers of coal are also present. These rocks are estimated to be 300-320 million years old. These formations generally tilt from the northeast down to the southwest (Prior, 1991). Bedrock is exposed only along the lower Chariton River Valley.

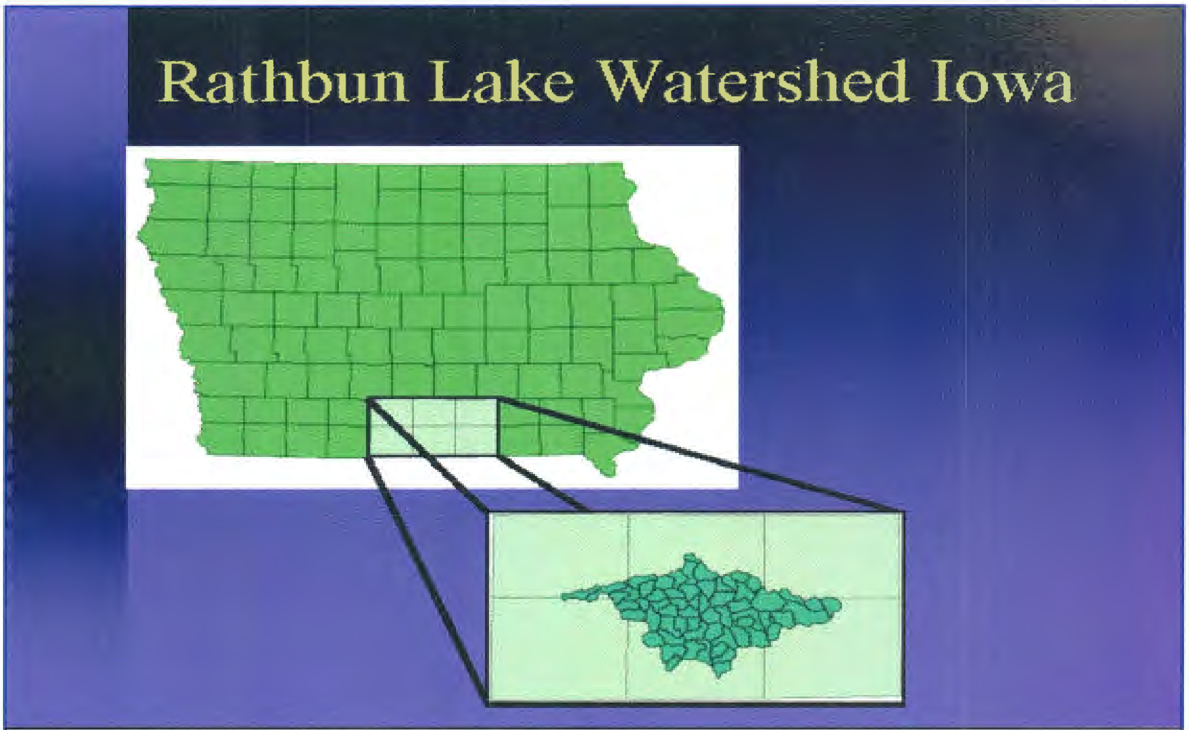

Figure 1 Rathbun Lake Watershed Location

Coal mining was a major industry in the area from the 1860s until the 1930s to supply coal to steam locomotives (Oelmann, 1984). However, coal mining steadily declined and is non-existent today. Limestone and gypsum quarrying are also possible. However, existing quarries are very limited. Limestone is mined only to provide construction-grade materials (Chariton Valley RC&D, 1972).

This area of Iowa is part of the Southern Iowa Drift Plain landform (Figure 2). Overlaying the bedrock is a thick mantle of unconsolidated material. This area is characterized by a loess

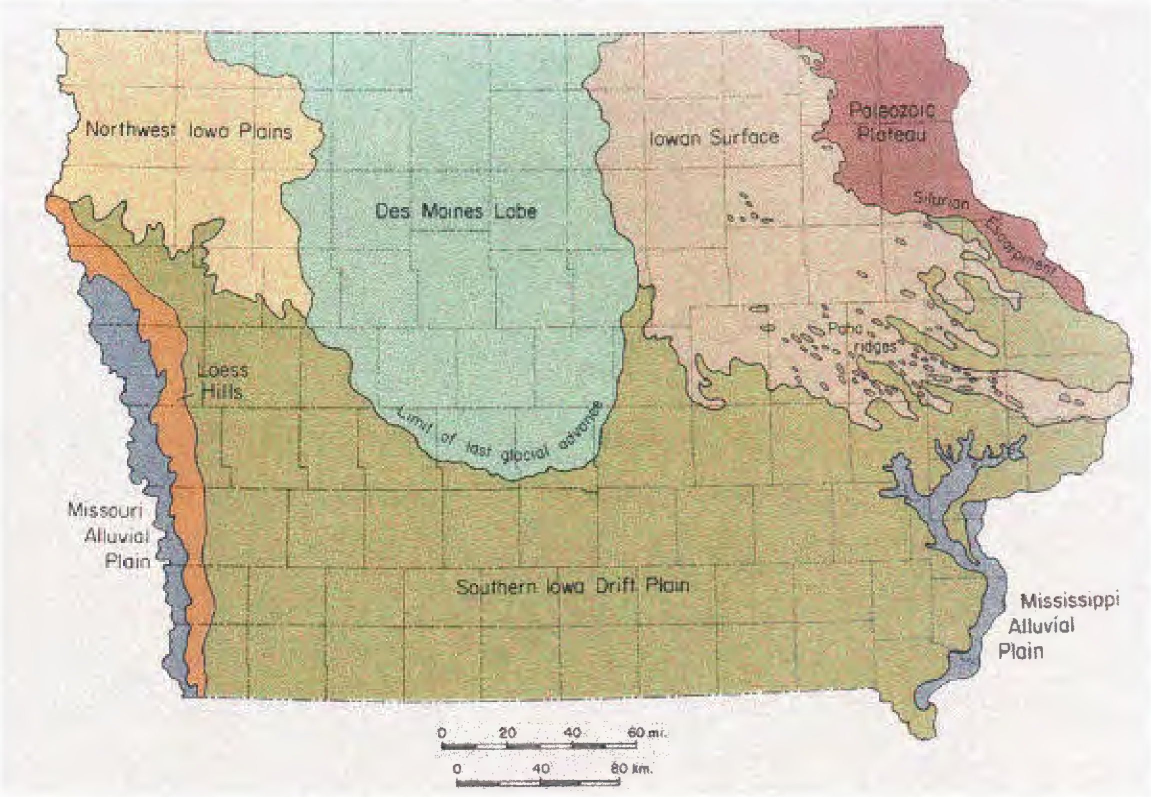

Figure 2 Landforms of Iowa (adapted from Prior, 1991)

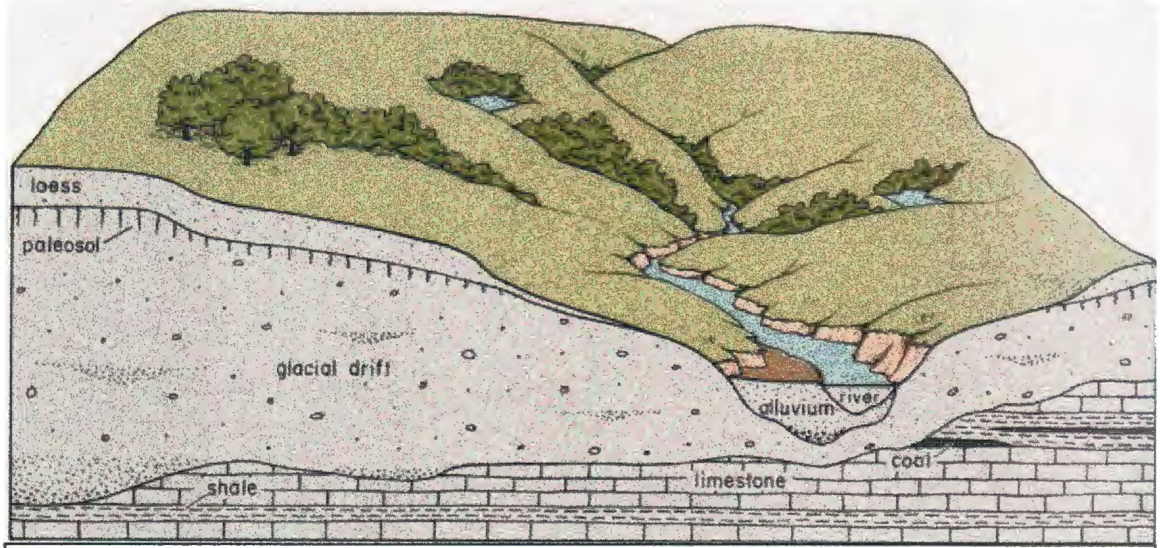

Figure 3 Southern Iowa Drift Plain (Adapted from Prior, 1991)

mantle up to 5-6 m thick on the upland divides over a highly developed paleosol (ancient soil) in pre-Illinoian glacial till (Figure 3). The glacial till generally extends to a depth of 38 meters in this area of the state. The loess is Wisconsin-age that originated from the Missouri River Valley. The paleosol is commonly called the Yarmouth-Sangamon because it developed during the Yarmouth and Sangamon interglacial periods and the Illinoian glacial period (Ruhe, 1969).

Soils. The major soil associations that comprise the Chariton River valley are the Adair-Grundy-Haig and the Adair-Seymour-Edina. The Adair-Grundy-Haig association is located on the upper (northern) part of the watershed. The Adair-Seymour-Edina association is located on the middle and lower portions of the watershed.

Adair soils formed in the exhumed late-Sangamon paleosol formed in glacial till and are moderately well to somewhat poorly drained. These soils are found on convex ridgetops and convex sideslopes. Grundy soils formed in loess and are somewhat poorly drained. These soils are found on convex ridgetops in the uplands. Haig soils formed in loess and are poorly drained. These soils are found on broad upland divides. Seymour soils formed in loess and are somewhat poorly drained. These soils are found on relatively short, convex ridges in the uplands. Edina soils formed in loess and are poorly drained. These soils are found on broad, planar, upland divides.

River Network. The Chariton River is part of the Missouri River Basin. The Chariton River has its headwaters in southeast Clarke County and flows in an easterly direction toward the town of Chariton. From Chariton, it flows in a southeasterly direction through southern Lucas County. It enters Appanoose County in the northwest corner and flows southeasterly until it exits near the southeast corner of the county. Major tributaries to the Chariton River that contribute flow to Rathbun Lake are the South Fork Chariton River that empties directly into the lake and Wolf Creek which empties into the Chariton River just above normal lake elevation southeast of Chariton.

Climate

Southern Iowa has a mid-continental climate. It is characterized by warm summers and cold winters. The following data is extracted from the Chariton weather station records from 1961-1990 (Midwest Regional Climate Center, 2000). Average temperature is 9.4 degrees Celsius (^{o}C). The monthly average temperature ranges from –7.1 ^{o}C in January to 23.9 ^{o}C in July. The frost-free growing season averages 155 days and occurs May 2 through October 1.

The area receives an average of 931 millimeters (mm) of precipitation annually. About 698 mm of snow falls on average. Approximately 70% of the precipitation is received during the growing season (April through September). Much of this rain is received during thunderstorm events. The five highest 24-hour rainfall totals received since 1960 are: 204 mm on September 13, 1961; 177 mm on September 15, 1992; 148 mm on August 8, 1970; 140 mm on July 5, 1993 and 139 mm on July 4, 1981 (Carlson and Todey, 2001).

Native Vegetation

Early post-European settlement surveys of the area indicate that the river valleys were typically forests of deciduous trees. Typical tree species included oak, ash, hickory, elm and maple. Uplands had a native vegetative cover of tall warm season grasses including big bluestem, switchgrass, and little bluestem (State Historical Company, 1881). These early land surveys were supported by the soil genesis and morphology characteristics of the soils described by soil scientists who later inventoried and classified the soils (Lockridge, 1971; Oelmann, 1984).

History

According to several historical references (State Historical Company, 1881; Western Historical Company, 1878), the first Europeans who traversed and explored the Chariton River valley area were soldiers, trappers, and Indian traders in the early 1830's. A group of Mormons traversing from Nauvoo, Illinois to Salt Lake City, Utah were the first documented

European settlers to temporarily inhabit Lucas County in 1846-47. This group established a winter camp on the edge of the trees in the Chariton River Valley just south of the present-day town of Chariton. The location of this settlement is called "Chariton Point", describing the pyramid-shape the Chariton River forms as it flows northeasterly and abruptly turns to a southeasterly course. The first documented permanent white settler moved to Appanoose County in 1838 and to Lucas County in the fall of 1847.

Early historical records describe the flooding potential of the Chariton River in the pioneering days (Western Historical Company, 1878). One story explains that a small building located on the bank of the Chariton River in T70N, R18W on the section line of sections 35 and 36 (in present-day northern Appanoose county) was used as a school during the winter of 1847-48. Unfortunately, the school term was not completed because floodwaters from the Chariton destroyed the building in the spring of 1848. Another story relates details of the flood of June 7, 1851 in which witnesses claim the Chariton River flooded its entire valley four feet deep. The flooding potential of the Chariton River continued to be a concern into the early 1900s. The Iowa State Planning Board completed a study in 1937 and recommended a series of smaller dams on the tributaries feeding into the Chariton River and a levy system on the Chariton River downstream in Missouri to address the flooding problem (Baldwin, 1937).

The flooding potential of the Chariton River continues to the present day. Over the twentieth century it perhaps even increased as landuse of the watershed changed from trees and warm season grass prairie to cool-season grass pastures and row crops. As part of the U.S. Army Corps of Engineers (ACE) water management plan of the Missouri River, Rathbun Dam was constructed and became operational in 1969. Rathbun Dam is a multi-purpose resource providing flood protection to 60,400 hectares downstream of the dam along the Chariton River. It also controls the water discharged downstream to enhance navigation on the Missouri and Mississippi Rivers (U. S. Army Corps of Engineers, 2001). Rathbun Lake supplies water to the Rathbun Regional Water Association, which, in turn, supplies water to approximately 50,000 people in southeast and south-central Iowa and northeastern Missouri (Southern Iowa Development and Conservation Authority, unpublished data, 1999). Rathbun

Lake is an outdoor recreation destination and also provides habitat for fish and game and non-game wildlife. Ensuring Rathbun Lake is able to continue meeting all of its designated uses is critical for the economic and environmental well-being of the area.

Excessive soil erosion, soil productivity decline, and impaired water quality are also historical, chronic concerns for the Chariton River Basin. Murray and Brown (1937) listed soil erosion as the single causative agent for economic decline. In their discussion, they identified the needs and costs for rehabilitating the four-county area of their study. In their conclusion, Murray and Brown stated (1937, p. 33), "the three outstanding needs are patience, hard work and cooperation." Also in 1937, the Chariton Basin Planning Board prepared a report and devised a plan to provide limestone and phosphate to all farmers in the Chariton Basin for free or at-cost. This report also contained recommendations to provide technical and financial assistance to farmers through local agencies for soil conservation and land management (Chariton Basin Planning Board, 1937). In 1978, to fulfill the requirements of the Clean Water Act section 208, a water quality management plan was prepared for the Chariton Valley region (French-Reneker-Associates, Inc., 1978b). Results of this study estimated 500,000 Mg of sediment was being delivered each year to Rathbun Lake. Fifty-eight percent was estimated to originate from cropland in the watershed.

Point source pollution, particularly failing septic systems or inadequate sewage treatment, have been other environmental issues of concern. Mayhew (1969) implicated the Chariton municipal sewage treatment plant as the cause of excessive biological oxygen demand (BOD) in a portion of the Chariton River downstream of the municipality. French-Reneker-Associates, Inc. completed an analysis of the existing and future needs for sanitary systems in the Chariton Valley area in 1978. This analysis was completed to fulfill the requirements of the Clean Water Act section 208. In these studies, human sewage was determined to be a primary point-source threat to water quality. Extensive sewage treatment systems, particularly around Rathbun Lake were proposed to solve the current sewage treatment problem and meet future needs (French-Reneker-Associates, Inc., 1978a).

Summary

Severe flooding, excessive soil erosion and impaired water quality have historically plagued the Chariton River Basin. Efforts to correct these problems in the past have been ineffective or lacked stakeholder involvement on a large scale. The introductions of mechanization and other technologies have changed the cropping systems from one based on forage production and pasture, to one with higher frequency of row crop corn and soybeans. According to the Iowa agricultural Statistics Service, from 1969 to 1997/99, soybean acreage increased 50% and cattle numbers declined 17% in the Chariton River Basin (Iowa Agricultural Statistics Service, 2001).

Objectives

This study will use a modeling approach to evaluate the current soil erosion, nutrient loading and pesticide loading for Rathbun Lake Watershed. The following section will provide a general overview of watershed models. Previously completed watershed modeling studies relevant to this study will be reviewed. Also, other work using the same model as this study will be reviewed and evaluated.

The objectives of this study are to:

1. Rank the 61 subbasins of Rathbun Lake Watershed on their relative sediment production, nutrient runoff and pesticide runoff using the Soil and Water Assessment Tool (SWAT).
2. Study the water quality effects of changing land use and management practices from baseline conditions to one of growing switchgrass for biomass production using the Soil and Water Assessment Tool.

Literature Review

Watershed model classification

Computer models are constructs of reality used extensively to help us understand the environment and the impacts we humans have on it. In order to more easily understand the real system, an idealized system is formulated to aid in our understanding. From this idealized system, models are constructed to emulate the idealized system. Watershed models can be classified many different ways by a series of hierarchical comparisons (Chow, 1972; Chow, et al. 1988; Maidment, 1993). The highest classification is that models are physically-based (material) or abstract. Physically-based models represent a physical system and are much simpler than an idealized system. An abstract model is one that is symbolic and is probably a mathematical representation of the idealized system (Tim, 1995).

Abstract models can be classified into theoretical or empirical classification based upon how the model simulates processes. Theoretical models simulate physical processes using scientific principles. Empirical models, on the other hand, formulate mathematical relationships between the input data and the observed results.

Theoretical models can be subdivided into deterministic or indeterministic (stochastic) classes. Deterministic models are constructed such that a given set of inputs will generate one (and only one) set of outputs. Indeterministic models provide a range of possible outcomes. This is accomplished when selected input data values are random based upon an expected mean and a probability distribution of that input data value. This concept is very useful when a model is desired to be used to generate a pollutant "not to exceed" value for Total Maximum Daily Loads, for example. The output for a stochastic model could be presented as a mean, range, and probability distribution for that range of output values.

Deterministic models can be further categorized as lumped or distributed based upon how the model conceptualizes space. A lumped model considers the physical system as a set of spatially homogeneous units and ignores the variability that occurs spatially. A distributed model treats the physical system as many small, discrete units each with a homogeneous set of input parameters.

Deterministic models can also be categorized by their treatment of time as event-based, or as continuous. An event-based model simulates the response to a single input parameter and holds the time and space domains constant. One of the most common input parameters used for this type of model is precipitation. Continuous models simulate a series of input events and the time and space domains are not constant. Continuous time models do have established time-step intervals that can vary from less than an hour, to a day, or longer.

The following hydrologic/water quality (H/WQ) assessment tools are listed to show the range of possibilities that exist among models and how they conceptualize the physical system they are designed to emulate. The Soil and Water Assessment Tool (SWAT) model (Neitsch et al., 1999; Neitsch, 2001) and the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) interface (U.S. EPA Office of Science and Technology, 2001) are each physically-based, theoretical, deterministic, distributed in space, and continuous in time. The Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS) (Beasley et al., 1980; Dillaha, 2001) and the Agricultural Nonpoint Source Pollution (AGNPS) (Young et al., 1987) models are physically-based, theoretical, deterministic, distributed in space, and event-based in time.

Watershed Model Use and Utility--Examples

SWAT was used for the Agricultural Research Service (ARS) Hydrologic Unit Modeling of the United States (HUMUS) project (Srinivasan et al., 1995). In this study, the contiguous United States were simulated at the 6-digit hydrologic unit code level to calculate a mass water balance. For this project, the predicted SWAT results were within 50 mm of measured stream discharge on 45% of the area and within 10 mm of the measured stream discharge on 18% of the area without any calibration. Kirsch and Kirsch, (2001) used SWAT to predict erosion and phosphorus loads for the 9,500 km^2 Rock River watershed in southern Wisconsin. This watershed had multiple point and nonpoint sources of pollution. The simulation setup had 116 subwatersheds and approximately 1,100 combinations of soils and land use to capture the variability within the watershed. In this study, SWAT predicted 41% of the phosphorus load was attributable to point sources of pollution and the remaining 59% attributable to nonpoint sources.

BASINS is an interface which integrates a geographic information system (GIS), national water quality modeling datasets and several assessment tools. It is to be used for urban and rural watersheds. An early application of BASINS has been to model contributions of stream discharge, sediment and nutrients for the Chesapeake Bay watershed (Donigan and Patwardhan, 1992). BASINS supports the development of Total Maximum Daily Loads (TMDLs). (US EPA, 2001). However, there is concern of how BASINS differentiates land uses by classifiying them as pervious or nonpervious to calculate runoff (U. S. Tim, personal communication, 17 March 1999).

AGNPS is an extensively used model for agricultural watersheds (U.S. EPA Office of Wetlands, Oceans, and Watersheds, 2000). Tim and Jolly (1994) used an Arc/Info interface with AGNPS to evaluate alternative management scenarios in a small (417 ha) watershed in southwest Iowa. Prato et al. (1989) used a GIS, AGNPS, and an economics optimization model to assess soil erosion, water quality, and farm net returns for 16 farms in a 4,563 ha watershed in Idaho.

GIS Linkages to SWAT

Several GIS interfaces have been developed. Srinivasan and Arnold (1994) developed a GRASS-SWAT interface. DiLuzio, et al. (1997) used ArcView GIS to develop an interface called ArcView SWAT. This interface has gone through many modifications and improvements. Bian, et al. (1996) developed an interface between Arc/Info and SWAT. This interface was unique in that it uses an internal object-oriented database. This object-oriented database is well-suited to link the two systems. Each of the hydrologic parameters is treated as a different class of objects. This enables the GIS to identify inconsistencies with the data, adding an element of intelligence to the data entry and editing processes. Other researchers have opted to use GIS independent of SWAT. Farrand used ArcView to build the model input files, but then loaded the files into the SWAT model manually via a UNIX platform (Todd Farrand, personal communication, 25 May, 2000).

Additional Research on SWAT Utility

In-stream kinetics are important to simulate when determining water quality parameters. Ramanarayanan et al. (1996) linked the in-stream water quality model QUAL2E to SWAT for the Wister Lake watershed in Oklahoma. Their preliminary findings are that SWAT did an acceptable job estimating stream water temperature and dissolved oxygen. But SWAT over predicted nitrogen concentration and under predicted phosphorus concentration. Ongoing studies will attempt to refine the model to better estimate the nutrient loading components. This type of linkage is invaluable if these tools are to be used as part of the EPA-sponsored TMDL program.

Spruill et al. (2000) conducted sensitivity analyses on fifteen input parameters to calibrate ArcView SWAT for predicting stream discharge. The optimum parameter value was determined by minimizing the average absolute deviation between measured and predicted stream discharge. The most sensitive model parameters for this watershed study in Kentucky included saturated hydraulic conductivity, alpha baseflow factor, recharge, drainage area, channel length, and channel width. In this study, daily stream flow was poorly predicted, even after calibration. However, the model predicted monthly stream flow acceptably. Hauck (1999) completed a sensitivity analysis on SWAT and concluded that the SCS curve number is the single most important input parameter.

Several researchers have investigated the impact subwatershed division schemes have on SWAT-simulated output. Bingner et al. (1996) evaluated SWAT using the Goodwin Creek watershed in northern Mississippi for a 10-year duration. This watershed of 21.31 km^2 drainage area had 14 stream monitoring stations installed, each representing an outlet of one or more subbasins. With this intensive monitoring network, SWAT was calibrated and was capable of simulating stream discharge with Nash-Sutcliffe coefficients, R^2, of about 0.80 for monthly average stream discharge. Raghuwanshi and Tripathi used a calibrated SWAT model on a watershed in India to study what effect changing subbasin size would have on simulated output. They determined that subbasin size and number did not appreciably affect simulated surface runoff. However, other components of the water balance (evapotranspiration, percolation, and soil water content) were impacted.

The SWAT model has been tested extensively for its utility and limitations. Harmel et al. (2000) reviewed three weather generators that could be used in SWAT and compared them to measured data and SWAT output. The weather generators compared were: USCLIMATE (Hanson et al., 1994), WXGEN (Nicks, 1974), and WGEN (Richardson and Wright, 1984) They concluded WXGEN was best able to match predicted rainfall to observed rainfall. WXGEN-generated rainfall best reproduced the total runoff SWAT-simulated volumes when using measured rainfall data. However, USCLIMATE performed better in reproducing SWAT-simulated peak runoff rates using the measured rainfall data.

Buland et al. (2001) successfully linked the Soil Survey Geographic Database (SSURGO) (USDA NRCS Soil Survey Division, 2000) soils data to SWAT for Johnson County, Iowa. Additionally, in this study, county level National Resource Inventory (NRI) data was used to develop annual land cover information for the SWAT model. A sub-model simulating pathogen loading, transport, and die-off routines has also been develop recently for SWAT (Sadeghi, 2001).

Tile flow component has been added and validation is underway (Arnold et al., 1999). Jaynes and associates are attempting to modify the SWAT model to respond to tile flow on a watershed basis. They are using the 5,130 ha Walnut Creek watershed in central Iowa for their study (Dan Jaynes, personal communication, 19 Nov. 2001).

SWAT Use in Iowa

SWAT was being used in Iowa on a limited basis when this project started in 1999. Now, several university researchers and government agency personnel are using the model. It is also being considered as a "tool of choice" for developing TMDLs (Total Maximum Daily Loads) for impaired waters within the state (U. S. Tim, ISU TMDL Working Group, personal communication, 2001).

Vache et al. (2001) used SWAT to predict relative environmental impacts from three futuristic agricultural land use/landscape scenarios for the year 2025. This work was completed for the Walnut Creek watershed southwest of Ames and Buck Creek watershed south of Grinnel. SWAT is used in the Walnut Creek watershed to validate the models' ability to predict drainage tile flow and tile water quality at the watershed scale (Dan Jaynes, personal communication, 19 Nov. 2001). Buland et al. (2001) completed a study on five watersheds in Johnson County where they linked SSURGO soils data and changed land use annually based upon the NRCS NRI as input data for SWAT. The SWAT model tile flow validation was completed at the Iowa State University Northeast Iowa Research Farm at Nashua (Arnold et al., 1999).

Materials and Methods

Computer modeling

Numerous computer models are available to predict water quality impacts from agricultural watersheds. The features of the computer model desired for this study were that it:

- be watershed-scale
- be continuous in time operation
- have the ability to develop and compare alternative management scenarios easily
- have sufficient resolution to compare the relative pollutant loading of the 61 subwatersheds
- be able to link to a GIS

With these features and the project objectives in mind, the Soil and Water Assessment Tool version 99.2 with the ArcView® (ESRI, Redlands, CA) interface (ArcView SWAT) was selected for this project. The specific version of the interface used is ArcView SWAT (beta) version 1.601.

SWAT

SWAT is a physically-based, semi-distributed, continuous, daily time step model designed to simulate water yield, sediment delivery, and nutrient and pesticide loading from large, ungaged watersheds. The model uses datasets typically available from government agencies. It is capable of predicting the relative impact of agricultural management and land use over long time periods.

The GIS interface of SWAT is set up as an extension of ArcView®. This configuration gives the interface the flexibility to use special features available in other ArcView® extension packages. The ArcView SWAT version of the model allows geo-referenced data to be preprocessed for entry into the model. After model simulation, the GIS component post-processes the model output and displays the data as graphics, charts or tables. This type of GIS interface is an example of close-coupling as explained by Tim (1995).

Key processes, which impact water quality, are discussed below.

Water Yield. The water balance is the basic driver of the model. The water balance equation used is:

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

where SW_t is the final soil water content (mm water), SW_0 is the initial soil water content (mm water) on day i, R_{day} is the amount of precipitation (mm water) on day i, Q_{surf} is the amount of surface runoff on day i (mm water), E_a is the amount of evapotranspiration on day i (mm water), w_{seep} is the amount of water entering the vadose zone from the soil profile on day *i* (mm water), and Q_{gw} is the amount of return flow on day *i* (mm water). Because SWAT uses a daily time step, the water balance is calculated every day of the simulation.

The water yield from a given land area is important because it heavily influences the concentration of pollutants being removed from the land area. The major component of water yield is surface runoff. The quantity of surface runoff impacts the amount of soil erosion that occurs.

Sediment Yield. The predicted soil erosion rate and sediment yield is calculated for each hydrologic response unit (HRU) with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). This equation uses surface runoff volume and peak rate to predict erosion rate and sediment delivery from small watersheds. MUSLE is derived from the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978). The MUSLE equation adapted for use in the model is:

$$Sed = 11.8 \cdot (Q_{surf} \cdot q_{peak} \cdot area_{hru})^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE}$$

where *Sed* is the sediment yield (metric tons), 11.8 is a unit conversion constant, Q_{surf} is the surface runoff volume (mm water/ha), q_{peak} is the peak runoff rate (m^3/s), $area_{hru}$ is the area of the hydrologic unit area (HRU) in hectares, K_{USLE} is the USLE soil erodibility factor, C_{USLE} is the USLE cropping and management factor, P_{USLE} is the USLE conservation support practices factor, and LS_{USLE} is the USLE slope length and steepness factor.

The Q_{surf} and q_{peak} are calculated every day precipitation occurs. If surface runoff occurs, then sediment yield is calculated for that day. Because crop growth affects Q_{surf} and q_{peak}, C_{USLE} is also updated daily to reflect changes in the plant growth and land cover.

Crop Growth. Crop growth is simulated in SWAT using the modeling approach used in the Erosion Productivity Impact Calculator (EPIC) (Williams et al., 1984). EPIC allows for the variation in growth for different plant species, and variation due to climate and growth conditions.

Pesticides. SWAT simulates the fate of pesticides applied to the soil surface and/or incorporated by tillage implements. The routines used are adapted from the model GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Leonard et al., 1987). Six chemical or physical properties of a pesticide are necessary in order to simulate its movement and transformation by SWAT.

Nutrients. Nitrogen and phosphorus management and movement are simulated in SWAT using the modeling approach of GLEAMS. SWAT simulates the movement and transformations of nitrogen between two mineral (ammonium and nitrate) and three organic (active, stable and fresh) soil nitrogen pools. Monitoring three mineral (labile in solution, labile on soil surface and fixed in soil) and three organic pools (active, stable and fresh) of soil phosphorus simulates soil phosphorus movement and transformation.

Adapting SWAT to Rathbun Lake Watershed

Utilizing ArcView SWAT requires obtaining, formatting and entering several spatial and non-spatial databases into the model.

Spatial Data

The spatial (GIS) databases and coverages are discussed first. All of the spatial coverages prepared for this project were acquired and formatted by Tyler Jacobsen, GIS Specialist with the Rathbun Rural Water Association (Tyler Jacobsen, personal communication, August 1999, December 1999, February 2000, July 2001).

Digitized Elevation Model (DEM). (Figure 4) The DEM is a graphical representation of the land slope steepness and aspect (direction). The DEM is prepared as a 30-meter grid polygon format. Each "cell" of this 30-meter by 30-meter grid is given a single elevation value. This GIS coverage determines watershed and subbasin (subwatershed) boundaries, and thus, water

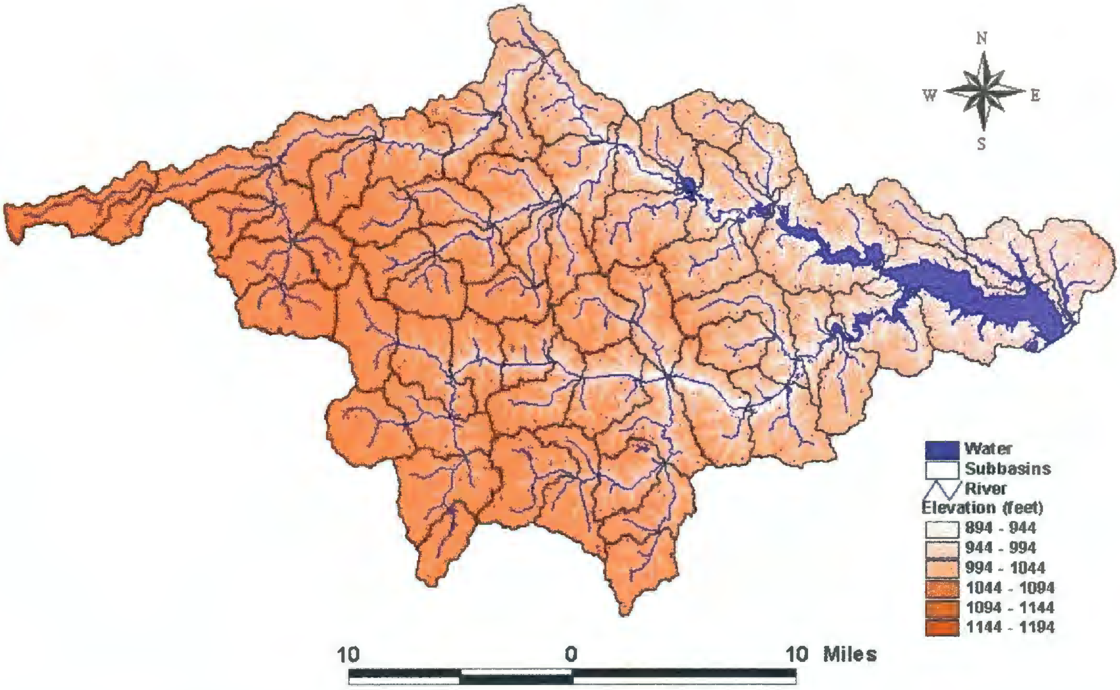

Figure 4 Digitized Elevation Model (DEM)

flow direction and accumulation. The DEM is available through the Iowa Department of Natural Resources Geological Services Bureau (IDNR-GSB).

Streams. The digitized streams are line representations of accumulated perennial water flow over the soil surface. This coverage is important for the routing (i.e. movement and transformation) of runoff and pollutants originating in the watershed. The stream coverage was created by the hydrologic modeling component of SWAT utilizing the DEM.

Subbasins delineation. Subbasin outlets are geo-referenced points on a stream or river identifying the outlet of the subbasin. Outlets may occur in series on larger streams such that the outlet of one subbasin contributes channelized flow to a downstream subbasin. A subbasin is the land area contributing surface runoff to its outlet. The subbasin file was created in-house following Natural Resources Conservation Service (NRCS) and USGS criteria for developing 14-digit Hydrologic Units. The file was not used directly in SWAT but was analyzed and an outlet point shape file was created for use in SWAT. This subbasin coverage created in SWAT closely matched a subbasin file previously created by the Chariton Valley Resource Conservation and Development (RC&D) staff for watershed management purposes.

Land use/land cover. (Figure 5) This coverage is a graphical representation of land cover type. The land use/land cover is prepared as a 30-meter grid polygon format. Each "cell" of this 30-meter by 30-meter grid is designated a single land cover type. This coverage is used to define the plant growth characteristics SWAT will use to simulate the area. This coverage is part of the USGS National Land Cover Dataset using 1992 Landsat thematic mapper imagery and supplemental data (USGS, 2000).

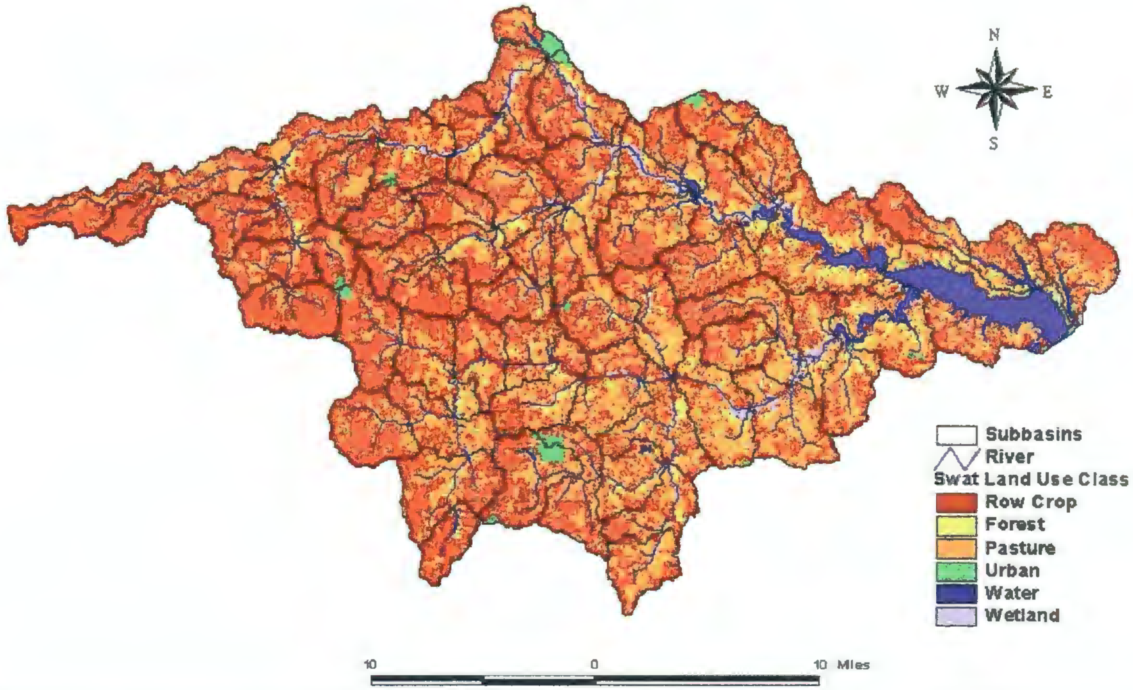

Figure 5 SWAT Land Use and Land Cover Coverage

Soils. (Figure 6) This coverage is a graphical representation of soil distribution. The soils coverage is prepared as a 30-meter grid polygon format. Each "cell" of this 30-meter by 30-meter grid is designated a single soil type. This coverage is used to define the soil chemical and physical properties SWAT will use to simulate the area. The township digital soil coverage of Appanoose, Clark, Decatur, Lucas, Monroe, and Wayne Counties and the Iowa Soil Properties and Interpretations Database (ISPAID) (Fenton, 2001) are the original sources of the information for the soils coverage. The Iowa soils data was linked to the SWAT soils database by use of the SCS Soils 5 column of ISPAID and the S5ID number from the soilsia.dbf in SWAT.

Figure 6 SWAT Soils Coverage

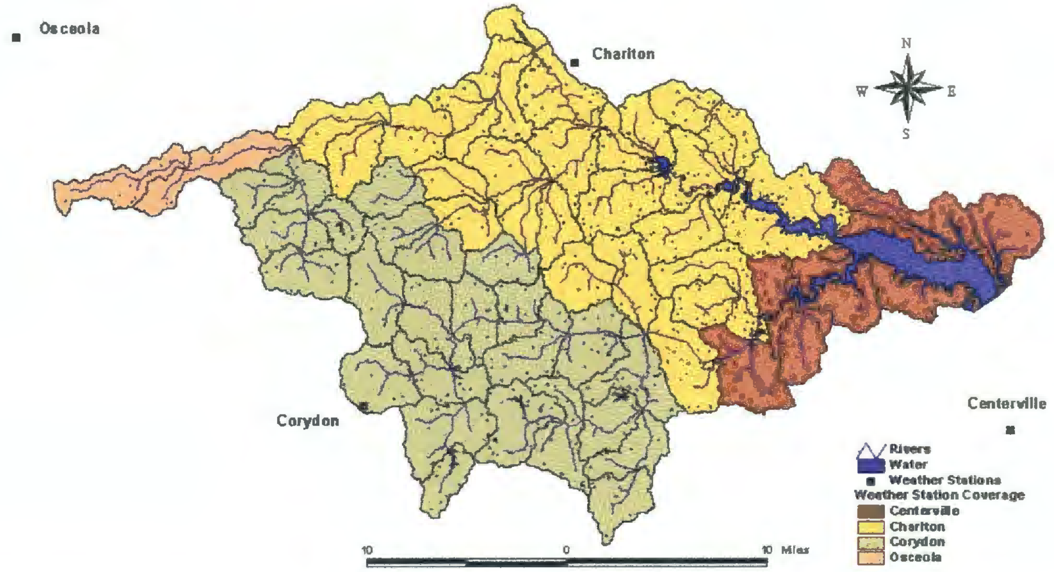

Figure 7 Weather Station Locations and Simulation Coverage

Weather. Three types of files are maintained to simulate weather. These files are the measured daily maximum and minimum temperature file, the measured daily precipitation file, and weather generator input file. The SWAT model comes complete with a climate generation model and the monthly average parameters for more than 1100 weather stations throughout the contiguous United States. For this project, measured daily maximum and minimum temperature and precipitation data from four long-term recording stations close to the watershed were obtained from Dennis Todey and used as input into the climate generator (Dennis Todey, personal communication, 1999). The monthly data for these recording stations were obtained from the Iowa State University Agronomy Department Agricultural Meteorology website at: http://www.agron.iastate.edu/climodat/. The weather stations are located near the towns of Centerville, Chariton, Corydon and Osceola. See Figure 7. SWAT simulates the weather by subbasin. If data from multiple weather stations is available, the distance from the centroid of each subbasin to each weather station is calculated. The subbasins are then assigned to the closest weather station for their respective climate data.

Non-spatial Data

Non-spatial data required by the model include several databases needed to develop management practice schedules.

Crop Database. The crop database taken from the EPIC model contains the growth parameters of approximately 100 plants or generic crop growth types. The growth parameters for switchgrass (*Panicum virgatum* L.) were obtained from an updated version of the EPIC obtained from Phil Gassman (Phil Gassman, personal communication, 2000) and from Ken Moore, Professor of Agronomy, at Iowa State University (Ken Moore, personal communication, 2000). Important plant growth parameter values for corn (*Zea mays* L.), soybeans (*Glycine max* L., Merr.), smooth bromegrass (*Bromus enermis* Leysser) and switchgrass are listed in Table 1. The complete definitions of the crop growth attributes are available from the SWAT User's Manual Version 99.2 p. 158-160 (Neitsch et al., 1999).

Table 1 Listing of Crops and Selected Crop Growth Attributes Used in the Scenarios

CROP NAME	BIO_E	HVSTI	T_OPT	T_BASE	BLAI	DLAI	CHTMX	RDMX
SOYBEAN	25.0	0.30	25.0	10.0	5.0	0.90	0.8	2.00
CORN	40.0	0.50	25.0	8.0	5.0	0.80	2.0	2.00
BROME GRASS	35.0	0.02	25.0	6.0	3.0	0.85	0.8	1.30
SWITCHGRASS	47.0	0.01	30.0	10.0	5.0	0.70	2.5	2.20

BIO_E	Radiation-use efficiency or biomass-energy ratio ((kg/ha)/(MJ/m2)).
HVSTI	Harvest Index. This is the plant yield of seed divided by the total aboveground biomass ((kg/ha)/(kg/ha)).
T_OPT	Optimal temperature for plant growth (deg C).
T_BASE	Minimum (base) temperature for plant growth (deg C).
BLAI	Maximum potential leaf area index.
DLAI	Fraction of growing season when leaf area declines (heat units/heat units).
CHTMX	Maximum canopy height (m).
RDMX	Maximum root depth (m).

Pesticide Database. The pesticide database in SWAT was obtained from the GLEAMS model pesticide database (Leonard et al., 1987). Six chemical or physical characteristics of a pesticide are needed to model its fate within SWAT. The characteristics are: water solubility, soil adsorption coefficient (k_{oc}), foliar half-life, soil half-life, application efficiency and washoff fraction. The database was edited to add atrazine and acetochlor. The pesticide characteristics needed as input into the model were obtained from the Herbicide Handbook of the Weed Science Society (Ahrens, 1995) and from R. Don Wauchope, USDA-ARS, Tifton, GA (R. Don Wauchope, personal communication, 2000). The six chemical and physical characteristics necessary for each pesticide to be modeled are listed in Table 2 for Harness® (acetochlor), atrazine, Roundup® (glyphosate), and 2,4-D. The definitions of the pesticide characteristics were obtained from the SWAT User's Manual Version 99.2 p. 163-164 (Neitsch et al., 1999).

Table 2 Listing of Pesticides and Pesticide Characteristics

PNAME	SKOC	WOF	HLIFE_F	HLIFE_S	EFA	WSOL
Atrazine	100	0.45	5.0	60.0	0.75	33
Harness	100	0.40	3.0	60.0	0.75	223
2, 4-D	74.0	0.45	9.0	10.0	0.75	900.0
Roundup	500.0	0.60	2.5	30.0	0.75	12000.0

SKOC	Soil adsorption coefficient normalized for soil organic carbon content (mg/kg)/(mg/L)
WOF	Wash-off fraction
HLIFE_F	Degradation half-life of the chemical on the foliage (days)
HLIFE_S	Degradation half-life of the chemical in the soil (days)
EFA	Application efficiency
WSOL	Solubility of the chemical in water (mg/L or ppm)

Fertilizer Database. The fertilizer database in SWAT contains 54 commonly available chemical fertilizers, organic fertilizers, and animal manures. To this database, a product called HLF fertilizer was added. This material is a by-product of a nearby corn lysine production plant (J. Sellers, Jr., personal communication, 2000). Table 3 lists the chemical and physical properties of fertilizers needed by the model for anhydrous ammonia (82-0-0), diammonium phosphate (18-46-0), urea (45-0-0) and HLF fertilizer. The definitions of the fertilizer characteristics were obtained from the SWAT User's Manual Version 99.2 p. 164-166 (Neitsch et al., 1999).

Table 3 Fertilizers and Selected Fertilizer Characteristics Used in the Scenarios

Fertilizer Name	FMINN	FMINP	FORGN	FORGP	FNH3N
Anhydrous Ammonia	0.82000	0.00000	0.00000	0.00000	1.00000
Urea	0.45000	0.00000	0.00000	0.00000	1.00000
Diammonium Phosphate	0.18000	0.20200	0.00000	0.00000	0.00000
HLF (lysine by-product)	0.05600	0.00000	0.01400	0.01000	1.00000

FMINN	Fraction of mineral N (NO3 and NH4) in fertilizer (kg min-N/kg fertilizer)
FMINP	Fraction of mineral P in fertilizer (kg min-P/kg fertilizer)
FORGN	Fraction of organic N in fertilizer (kg org-N/kg fertilizer)
FORGP	Fraction of organic P in fertilizer (kg org-P/kg fertilizer)
FNH3N	Fraction of mineral N in fertilizer applied as ammonia (kg NH3-N/kg min-N)

Implementing SWAT to Rathbun Lake Watershed

Because SWAT is a semi-distributed model, it can simulate discrete, small homogeneous areas within a subbasin. However, to effectively use this small-scale capability, one must know the assumptions made within the model and the limitations imposed due to the variability of each of the inputs and the resolution of the spatial databases. The amount of detail required of the model will be determined, in part, by selected project objectives. The two objectives of this study were to (1) rank the 61 subbasins in the watershed based upon their relative environmental impact, and (2) compare the relative environmental impact of various management scenarios.

<u>Delineating Hydrologic Response Units.</u> Hydrologic Response Units (HRUs) are the unique combinations of land use and soil that occur within an individual subbasin. The SWAT model allows the user to select how an HRU is defined (Figure 8). One option is to select the predominant land use and predominant soil for each subbasin. This would then be a single HRU for each subbasin. The second option available to the modeler, is to select multiple HRUs. This option is accomplished by moving adjustable threshold scale bars for land use and soil that define the threshold criteria. To develop a multiple HRU option, the threshold for land use is first selected. The sliding threshold scale bar ranges from 1% to the maximum percent of any land use in any subbasin in the watershed. For example, if 10% threshold for land use is selected, this means that within each subbasin, only those land uses that have at

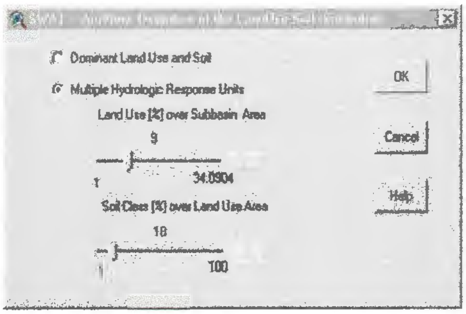

Figure 8 Selecting the Hydrologic Response Unit (HRU)

least 10% areal coverage in the subbasin will be used to define HRUs. Land uses comprising less than 10% areal coverage within the subbasin will not be simulated. The land area where these minor land uses exist will be distributed back to the remaining land uses in relative proportion to the initial extent of these land uses within the subbasin. This last step is done so that all of the land within a subbasin will have an HRU assigned to it.

The same procedure is applied regarding the threshold selection for soils. However, when selecting the soils threshold level, the threshold applies to the areal extent of the soils within a specific land use within a subbasin. The scale bar for soils ranges from 1% to the maximum extent of any soil within any land use within any subbasin. The scale bars of the land use and soils operate independently of each other. Therefore, one can select 10% land use threshold and 20% soil threshold, for example.

The multiple HRU option was selected for this project. The threshold limits set for creating HRUs was 9% land use and 10% soils. This resulted in creating and simulating 513 HRUs within the 1,427 km^2 watershed for the baseline scenario. These thresholds were selected for this project based upon the detail of the land use coverage, the detail of the soils coverage, and the project objectives. Table 4 relates how the multiple HRU land use threshold affects how the model "sees" the minor uses compared to the GIS data.

Table 4 Comparison of the GIS Land Use Coverage and SWAT-Modeled Coverage of Minor Land Uses

Land Use	GIS Base Coverage (ha)	1% SWAT Threshold (ha)	9% SWAT Threshold (ha)
Forest (mixed, deciduous)	13,536	13,574 (100%)	10,505 (78%)
Urban (residential, quarries commercial, urban grass, barren rock)	3,010	2,856 (95%)	538 (19%)
Wetland (wooded, herbaceous)	6,798	6,798 (100%)	1,752 (26%)
Water	5,455	5,113 (94%)	4,424 (81%)

The multiple HRU option determines the number of unique land use and soil combinations simulated, and therefore, the amount of detail to be simulated. The smallest area theoretically to be simulated can be calculated as:

Average subbasin area X percent land use threshold X percent soil threshold = smallest area theoretically simulated.

For this project, that area would be:

2,340 ha. average subbasin area X 9% HRU land use threshold X 10% HRU soil threshold = ~ 21 ha.

Management Practice Schedules. Management practice schedules are the detailed cultural and management practices applied to a specific land use in the watershed. In this study, one management practice schedule is applied to all of a given land use within the watershed. Agricultural Land, Pasture/Hay land and Switchgrass have locally developed management practice schedules applied to them. These schedules were developed with input from local farmers and government agency staff familiar with farming practices in the watershed. Other land uses (e.g. Forest, Wetlands) have model-generated default management practice schedules applied. Figures 9 and 10 illustrate how management practice schedules are inputted into the model. The management practice schedules can be scheduled either by date or by heat units. When scheduling practices by date, the model simulates that cultural practice on the date specified every year. When scheduling practices by heat units, the model simulates that cultural practice on the date when sufficient heat units have accumulated for the specified year.

The locally developed management practice schedules for Agricultural Land, Pasture/Hay land and Switchgrass are detailed in Tables 5, 6 and 7.

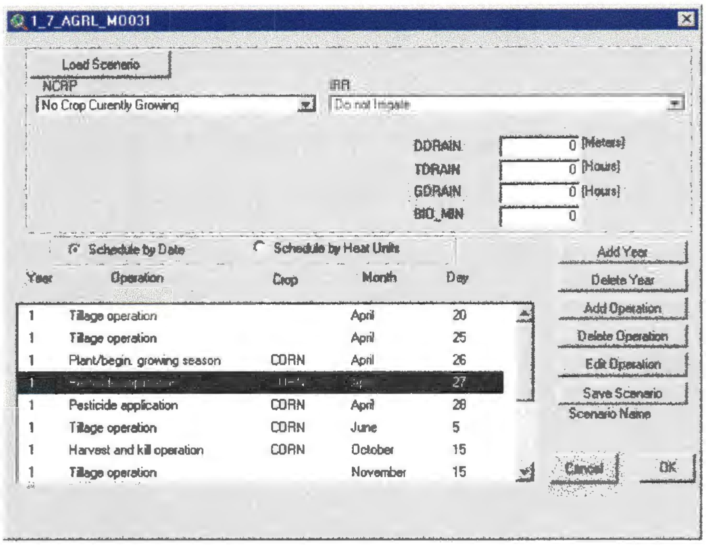

Figure 9 Management Practice Schedule First Data Entry Window

<u>Scenarios Defined.</u> Two SWAT projects were established, simulated and analyzed to measure the observed impacts of altering land management. One project scenario, which we will call "baseline," simulates the existing conditions of the watershed. The second project scenario, which we will call "switchgrass," simulates an alternative land use converting agricultural land to switchgrass for biomass production. The Chariton Valley RC&D staff developed the switchgrass scenario. It converts agricultural land with relatively high erosion and/or leaching potential to switchgrass for biomass production on approximately 21,700 ha. The criteria for the erosion potential is the Erodibility Index (EI) value of >50. The criteria for the leaching potential is Leaching Index >= 5. The Erodibility Index is defined to be the

value of (RxKxLS)/T (from the Universal Soil Loss Equation), where R is a measure of rainfall and runoff, K is a factor of the susceptability of the soil to water erosion, and LS is a measure of the combined effects of slope length and steepness. The Leaching Index uses the soil hydrologic group and mean annual precipitation to estimate the amount of water that will potentially leach below the root zone. Figure 11 shows the areas of agricultural land converted to switchgrass for biomass production for the switchgrass scenario.

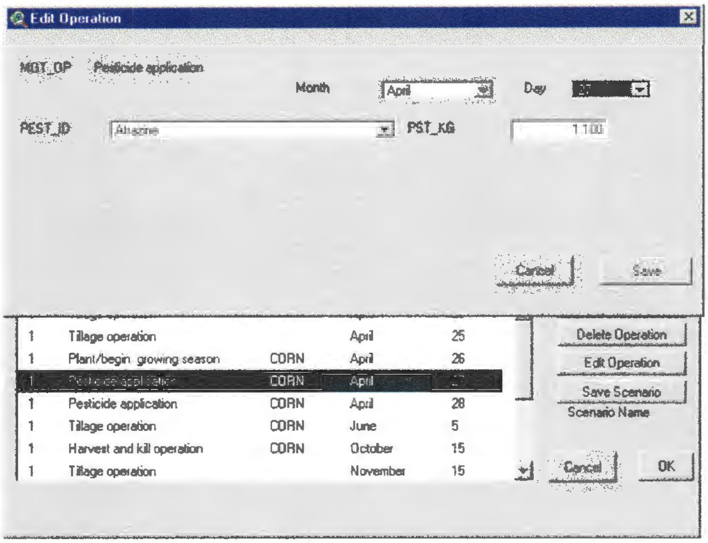

Figure 10 Management Practice Schedule Second Data Entry Window

Table 5 Agricultural Land Management Practice Schedule

Year	Operation	Crop	Month	Day	Description
1	Tillage		April	20	Field cultivate
1	Tillage		April	25	Field cultivate
1	Begin growing season	Corn	April	26	Plant
1	Pesticide	Corn	April	27	Atrazine @ 1.1 kg/ha
1	Pesticide	Corn	April	28	Harness @ 2.8 kg/ha
1	Tillage	Corn	June	5	Row cultivate
1	Harvest and kill	Corn	October	15	Harvest for grain
1	Tillage		November	15	Coulter chisel plow
2	Tillage		April	15	Tandem disk
2	Tillage		May	10	Field cultivate
2	Begin growing season	Soybeans	May	11	Plant
2	Pesticide	Soybeans	June	15	Roundup @ 0.56 kg/ha
2	Harvest and kill	Soybeans	October	1	Harvest for grain
2	Fertilizer		November	10	Anhydrous ammonia @ 168 kg/ha
2	Fertilizer		December	1	Diammonium phosphate @ 146 kg/ha

Table 6 Pasture/Hay Land Management Practice Schedule

Year	Operation	Crop	Heat Unit Proportion	Description
1	Fertilize		0.004	Urea @ 146 kg/ha
1	Begin growing season	Smooth brome grass	0.02	
1	Grazing operation	Smooth brome grass	0.1	30 days grazing, 16.8 kg/ha/day biomass dry matter consumed, 4.8 kg/ha/day dry beef manure produced
1	Grazing operation	Smooth brome grass	0.39	30 days grazing, 16.8 kg/ha/day biomass dry matter consumed, 4.8 kg/ha/day dry beef manure produced
1	Grazing operation	Smooth brome grass	0.75	30 days grazing, 16.8 kg/ha/day biomass dry matter consumed, 4.8 kg/ha/day dry beef manure produced

Table 7 Switchgrass for Biomass Management Practice Schedule

Year	Operation	Crop	Month	Day	Description
1	Begin growing season	Switchgrass	May	15	
1	Fertilize	Switchgrass	June	1	High lysine corn bi-product @ 1900 kg/ha
1	Pesticide	Switchgrass	June	2	Atrazine @ 1.68 kg/ha
1	Pesticide	Switchgrass	June	3	2,4-D @ 1.12 kg/ha
1	Harvest only	Switchgrass	October	25	Harvest index = 0.80

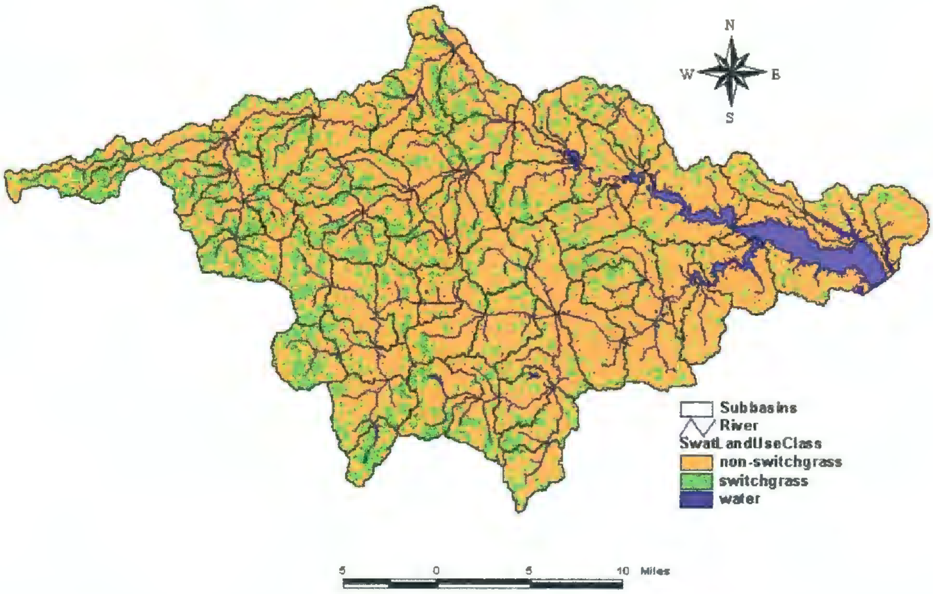

Figure 11 Areas of Agricultural Land Converted to Switchgrass for Biomass Production – Switchgrass Scenario

Baseline Water Yield Compared to Measured Water Yield. The SWAT model water yield prediction was compared to measured stream flow from USGS stream gage #06903400 on the Chariton River near the town of Chariton. The years of comparison were 1966-1986 (21 years of data). The basis of comparison was yearly average stream flow. SWAT was "calibrated" for this area by adjusting selected parameters that resulted in predicted water flow to acceptably approximate observed flow. According to Loague and Green, (1991, p. 58), "A model's performance is judged acceptable if it is not possible to reject the hypothesis of no difference between observed and predicted values." To evaluate the null hypothesis that there was no difference between the observed and predicted stream flow for this project, a t-test was completed using the average annual stream flows from 1966-1986. The t-statistic was calculated as follows:

$$t_{calculated} = \frac{\bar{x} - \bar{y}}{s/\sqrt{n}}$$

where $\bar{x}$ = the average of the predicted stream flow values, $\bar{y}$ = the average of the observed stream flow values, s is the standard deviation of the predicted stream flow values, and n is the number of observations (years). The t-statistic calculated is $|0.617|$. The tabular t-statistic at 0.05 probability and 20 degrees of freedom is 1.725. Based upon these t-statistic values, the null hypothesis cannot be rejected, that is, there is no difference between the observed and predicted stream flow. Figure 12 graphically displays the observed vs. predicted average annual stream flow. It is noted that the years 1973 and 1982 appear as outliers to the rest of the data. Both years exceeded long-term average precipitation by 50% and 43% respectively. No other years included in this dataset approached that extreme. However, 1973 and 1982 were included with the statistical analysis because the data appears to be correct.

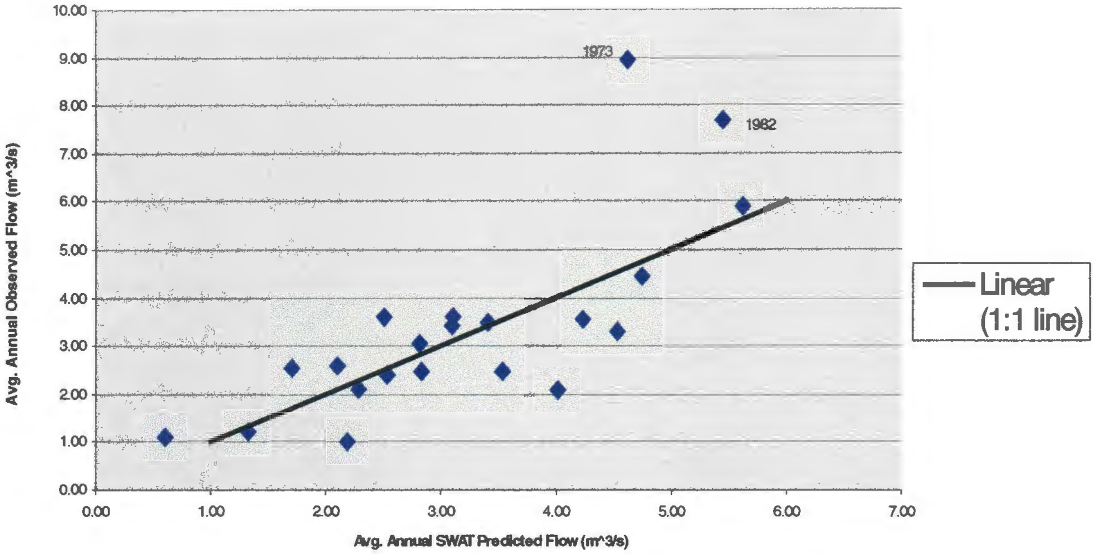

Figure 12 Chariton River Gage #06903400 Observed vs. SWAT Predicted Flow

Several model performance measures were calculated based upon the "calibrated" model comparing the average annual measured stream flow in cubic meters per second (m^3/s), to the predicted water yield as discussed by Loague and Green (1991). These calculated performance measures are listed in Table 8.

With the model adjusted for water yield from the initial run, the model then simulated 1987-1999 (13 years) with no additional alterations made to the model. Performance measures were again calculated comparing the average annual measured stream flow measured as m^3/s and predicted water yield over this time span. The calculated performance measures are listed in Table 8.

Table 8 SWAT Performance Measures

Performance Measure	"Ideal Value"	Calculated Value 1966-1986	Calculated Value 1987-1999
Maximum Error (ME)	0	4.32	4.22
Root Mean Square Error (RMSE)	0	38	40
Modeling Efficiency (EF)	1	0.56	0.59
Coefficient of Determination (CD)	1	2.19	3.03
Coefficient of Residual Mass (CRM)	0	0.05	0.17

If x_i = predicted value and y_i = observed value, $\bar{y}$ = average of the y_i values, and N is the number of observations, then:

Maximum Error (ME) =

$$ME = \max\left|x_i - y_i\right|$$

Root Mean Square Error (RMSE) =

$$RMSE = \frac{100}{\bar{y}}\left[\frac{\sum_{i=1}^{N}(x - y_i)^2_i}{N}\right]^{0.5}$$

Modeling Efficiency (EF) =

$$EF = \frac{\left[\sum_{i=1}^{N}(y_i - \bar{y})^2 - \sum_{i=1}^{N}(x_i - y_i)^2\right]}{\sum_{i=1}^{N}(y_i - \bar{y})^2}$$

Coefficient of Determination (CD) =

$$CD = \frac{\sum_{i=1}^{N}(y_i - \bar{y})^2}{\sum_{i=1}^{N}(x_i - \bar{y})^2}$$

Coefficient of Residual Mass (CRM) =

$$\mathrm{CRM} = \frac{\left[\sum_{i=1}^{N} y_i - \sum_{i=1}^{N} x_i\right]}{\sum_{i=1}^{N} y_i}$$

Simulation Setup. The management practices schedules listed above are applied to their respective land use category to all subbasins. Initial conditions included setting fraction of soil water field capacity in the basin file to 0.6 and all other adjustments made during the calibration process. The simulation period for all the output maps discussed below is 1990-1999 inclusive. This time frame was selected because the model GIS land use coverage (from 1992) most closely approximates the current watershed land use. The revised crop, pesticide, fertilizer, and weather databases discussed earlier were used. Model output is presented as average annual output for the ten-year period.

Results

The results of the modeling component of the project are presented as a series of tables and maps produced from the SWAT model simulated output. The SWAT model is a tool watershed planners and others can use to understand the processes occurring in the watershed and what relative changes can be expected by manipulating the model inputs. Observed differences between the baseline and switchgrass scenarios are responses to the overall impact of adding an additional landuse to the model setup. Although the HRU thresholds for landuse and soil may remain the same, the change in the landuse distribution may alter the relative percentages of the landuses and which soil types are simulated. Differences between scenarios may be due to the switchgrass being simulated, different HRUs being created, or both. Although the model may give a particular output in absolute terms, it should be understood that the output is more meaningful in relative terms by comparing one management scenario to another, for example.

Table 9 provides the subbasin ranking of six output parameters discussed for the baseline scenario. Table 10 provides the subbasin ranking of the same output parameters for the switchgrass scenario. Figure 13 identifies the subbasin numbers referred to in the following tables, results and discussion. Figures 14-19 compare the distribution of the outputs listed in tables 9 and 10 and illustrate the differences between the baseline and switchgrass scenarios. These bar charts graphically show the potential relative environmental benefits that growing switchgrass for biomass has on Rathbun Lake watershed.

Figure 13 Subbasin Identification Numbers

Table 9 Selected SWAT-Generated Output -- Baseline Scenario
Sorted by Output Columns, Maximum to Minimum Values

SUB*	WYLD** mm/yr	SUB	SYLD+ Mg/ha/yr	SUB	ORGN++ kg N/ha/yr	SUB	SEDP# kg P/ha/yr	SUB	NSURQ@ kg N/ha/yr	SUB	SOLP% kg P/ha/yr
4	250	9	44	9	50	9	9	23	7.8	37	0.6
59	233	38	38	37	40	21	8	26	7.5	2	0.6
37	225	36	34	24	40	37	8	38	7.5	53	0.6
2	224	53	33	38	39	4	8	27	6.7	30	0.6
53	222	48	31	4	39	38	8	49	6.5	25	0.6
25	222	24	30	30	36	24	8	42	6.5	52	0.6
29	222	40	30	21	36	59	7	53	6.4	6	0.6
49	218	18	30	2	34	14	7	2	6.3	29	0.6
52	218	49	29	35	33	41	7	20	6.3	49	0.6
32	211	4	29	29	33	26	7	25	6.2	4	0.5
31	206	37	29	41	33	2	7	43	6.1	40	0.5
27	206	30	29	33	33	33	7	37	6.1	46	0.5
9	206	35	28	59	32	30	7	31	6.0	9	0.5
17	206	29	28	14	32	27	7	5	6.0	35	0.5
6	205	43	27	52	32	23	7	56	5.9	18	0.5
30	204	58	27	53	31	44	6	50	5.8	31	0.5
18	203	8	26	25	31	25	6	60	5.7	58	0.5
46	203	46	26	8	31	29	6	29	5.7	15	0.5
40	201	52	26	18	31	28	6	4	5.6	26	0.5
24	197	25	26	36	30	56	6	11	5.6	8	0.5
48	196	21	25	26	30	52	6	30	5.5	24	0.5
26	195	2	25	40	30	18	6	52	5.5	33	0.5
3	193	10	25	7	29	35	6	40	5.4	48	0.5
22	193	42	24	48	29	5	6	12	5.3	34	0.5
38	192	39	24	13	28	40	6	46	5.3	59	0.5
33	187	31	24	10	28	13	6	51	5.3	27	0.5
23	187	47	24	28	28	12	6	47	5.3	42	0.5
8	187	16	23	44	28	8	6	18	5.2	17	0.5
35	187	51	22	5	27	53	6	32	5.2	47	0.5
58	185	33	22	27	27	7	6	15	5.1	7	0.5
42	184	41	22	56	26	36	6	6	5.1	50	0.5
34	184	50	22	23	25	10	5	57	5.0	43	0.4
36	181	34	22	12	25	48	5	9	4.9	38	0.4
21	179	56	22	50	25	19	5	58	4.9	36	0.4
5	178	7	21	16	24	50	5	35	4.8	5	0.4
7	177	17	21	42	24	42	5	19	4.8	12	0.4
47	177	57	21	34	24	51	5	48	4.8	32	0.4
15	176	5	21	51	24	54	5	59	4.7	23	0.4
61	175	59	21	54	24	16	5	17	4.7	51	0.4
43	173	14	20	22	24	20	5	28	4.7	21	0.4
12	173	32	20	46	23	11	5	8	4.6	56	0.4
51	172	22	20	55	23	22	5	39	4.5	16	0.4
19	166	45	19	17	22	55	4	34	4.5	3	0.4

Table 9. (continued)

SUB*	WYLD** mm/yr	SUB	SYLD+ Mg/ha/yr	SUB	ORGN++ kg N/ha/yr	SUB	SEDP# kg P/ha/yr	SUB	NSURQ@ kg N/ha/yr	SUB	SOLP% kg P/ha/yr
41	166	26	19	19	21	34	4	16	4.5	41	0.4
16	165	44	19	43	21	46	4	33	4.4	39	0.4
1	159	54	19	31	21	60	4	24	4.4	20	0.4
56	156	23	18	11	21	43	4	36	4.4	54	0.4
10	154	13	18	49	21	17	4	45	4.3	19	0.4
50	152	55	18	20	20	57	4	21	4.2	10	0.4
39	150	19	17	57	20	31	4	7	4.1	55	0.4
54	147	6	17	39	20	39	4	14	4.1	60	0.4
55	145	20	17	47	19	49	4	13	3.8	11	0.3
11	142	28	17	60	19	45	4	22	3.6	22	0.3
20	140	27	16	45	18	47	4	44	3.6	45	0.3
45	132	15	16	58	17	3	4	41	3.5	13	0.3
14	131	12	15	32	17	32	3	3	3.5	57	0.3
60	127	60	15	6	16	6	3	1	3.4	14	0.3
57	126	11	13	3	15	58	3	10	2.9	28	0.3
44	123	61	11	61	14	15	3	54	2.8	61	0.3
28	122	3	9	15	14	61	2	55	2.8	1	0.3
13	117	1	7	1	8	1	2	61	2.5	44	0.3

* Subbasin number
** Water yield
\+ Sediment yield
++ Organic nitrogen yield attached to the sediment
\# Phosphorus yield attached to the sediment
@ Soluble nitrogen yield
% Soluble phosphorus yield

Table 10 Selected SWAT-Generated Output -- Switchgrass Scenario Sorted by Output Columns, Maximum to Minimum Values

SUB*	WYLD** mm/yr	SUB	SYLD+ Mg/ha/yr	SUB	ORGN++ kg N/ha/yr	SUB	SEDP# kg P/ha/yr	SUB	NSURQ@ kg N/ha/yr	SUB	SOLP% kg P/ha/yr
4	223	9	25	9	33	9	6	49	5.1	6	0.5
32	217	4	20	4	26	37	5	31	5.0	49	0.5
49	217	49	19	37	25	4	5	53	4.6	53	0.5
59	210	40	19	21	23	21	5	47	4.5	30	0.5
31	209	36	18	24	22	24	5	6	4.3	58	0.5
29	204	38	18	59	21	29	4	2	4.2	37	0.5
53	201	53	18	29	21	59	4	37	4.2	31	0.5
37	201	18	17	30	21	2	4	32	4.1	2	0.4
2	200	31	17	53	20	5	4	58	4.0	46	0.4
17	200	48	17	2	20	30	4	30	4.0	52	0.4
6	196	47	17	35	20	14	4	20	4.0	29	0.4
46	193	46	17	5	20	53	4	25	3.9	47	0.4
52	192	37	16	14	20	38	4	26	3.9	25	0.4
25	189	39	16	33	19	40	4	43	3.9	17	0.4
30	185	58	16	40	19	35	4	46	3.9	34	0.4
47	184	43	16	38	18	33	4	17	3.9	35	0.4
40	183	42	16	7	18	18	4	29	3.8	40	0.4
22	183	29	16	52	18	25	4	50	3.8	8	0.4
9	182	57	16	36	17	26	4	52	3.7	32	0.4
3	177	51	15	8	17	7	4	42	3.6	33	0.4
18	177	35	15	26	17	41	4	60	3.5	15	0.4
58	176	24	15	41	17	56	4	39	3.4	39	0.4
26	173	30	15	18	17	52	4	34	3.4	42	0.4
33	173	32	15	25	17	48	4	4	3.3	50	0.4
42	172	8	15	48	17	36	4	33	3.3	48	0.4
24	170	21	14	54	16	44	4	35	3.3	9	0.3
34	170	5	14	42	16	8	4	5	3.3	18	0.3
5	169	56	14	51	16	51	3	40	3.2	4	0.3
48	169	59	14	56	16	42	3	15	3.2	7	0.3
35	168	14	14	49	16	46	3	8	3.2	43	0.3
61	167	2	14	46	16	54	3	51	3.1	24	0.3
8	166	25	13	31	15	31	3	57	3.1	26	0.3
7	164	52	13	44	15	27	3	45	2.9	51	0.3
43	163	7	12	34	15	57	3	48	2.9	36	0.3
27	163	54	12	22	15	19	3	18	2.9	5	0.3
21	160	50	12	10	15	49	3	23	2.8	16	0.3
1	159	17	12	39	15	23	3	1	2.8	3	0.3
19	155	10	12	17	15	17	3	16	2.7	20	0.3
36	155	19	12	57	15	28	3	56	2.7	22	0.3
51	155	34	12	58	14	13	3	22	2.7	61	0.3
39	153	33	12	27	14	10	3	7	2.7	54	0.3

Table 10. (continued)

SUB*	WYLD** mm/yr	SUB	SYLD+ Mg/ha/yr	SUB	ORGN++ kg N/ha/yr	SUB	SEDP# kg P/ha/yr	SUB	NSURQ@ kg N/ha/yr	SUB	SOLP% kg P/ha/yr
38	149	45	12	43	14	34	3	9	2.7	45	0.3
12	145	41	12	11	14	22	3	38	2.6	55	0.3
23	143	22	12	28	14	39	3	11	2.6	56	0.3
16	142	16	11	47	14	50	3	36	2.6	60	0.3
15	139	44	11	13	14	43	3	19	2.6	12	0.3
56	138	20	11	12	13	11	3	24	2.5	19	0.3
54	134	26	11	50	13	12	3	61	2.5	21	0.3
50	134	60	11	32	13	60	3	12	2.4	57	0.3
57	129	61	10	19	13	32	3	28	2.3	59	0.3
10	128	23	10	61	13	58	3	59	2.3	38	0.3
41	127	15	10	55	13	20	3	21	2.3	10	0.2
55	127	11	9	23	12	47	3	3	2.3	1	0.2
11	125	13	9	60	12	55	3	13	2.2	23	0.2
20	123	55	9	45	12	45	3	27	2.2	41	0.2
45	121	27	9	16	12	16	3	14	2.0	11	0.2
14	113	28	9	20	12	6	2	55	1.9	27	0.2
60	113	6	9	6	10	61	2	10	1.7	28	0.2
44	105	12	9	15	9	15	2	54	1.6	14	0.2
28	104	3	5	3	8	3	2	41	1.6	13	0.2
13	94	1	5	1	5	1	1	44	1.5	44	0.2

* Subbasin number

** Water yield

\+ Sediment yield

++ Organic nitrogen yield attached to the sediment

\# Phosphorus yield attached to the sediment

@ Soluble nitrogen yield

% Soluble phosphorus yield

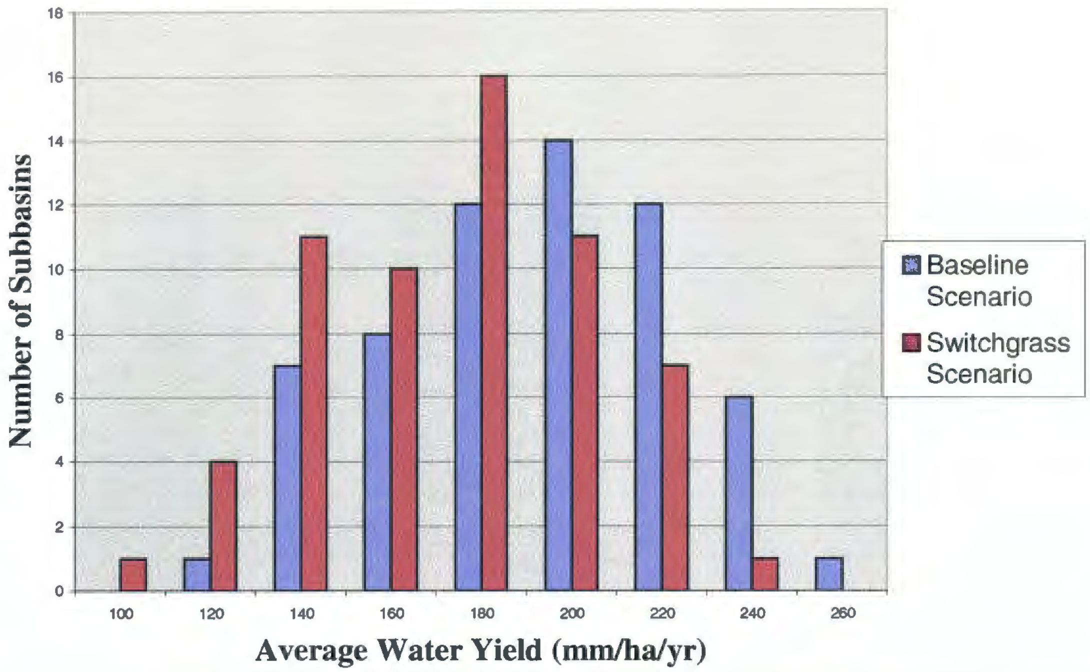

Figure 14 Average Water Yield Frequency Distribution

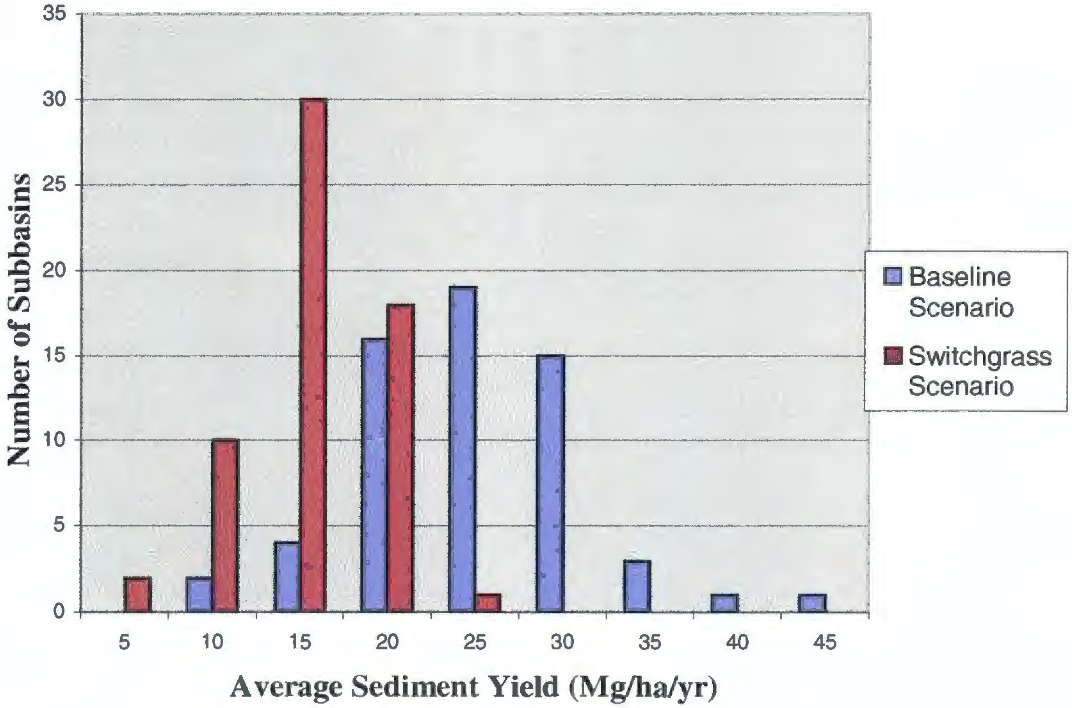

Figure 15 Average Sediment Yield Frequency Distribution

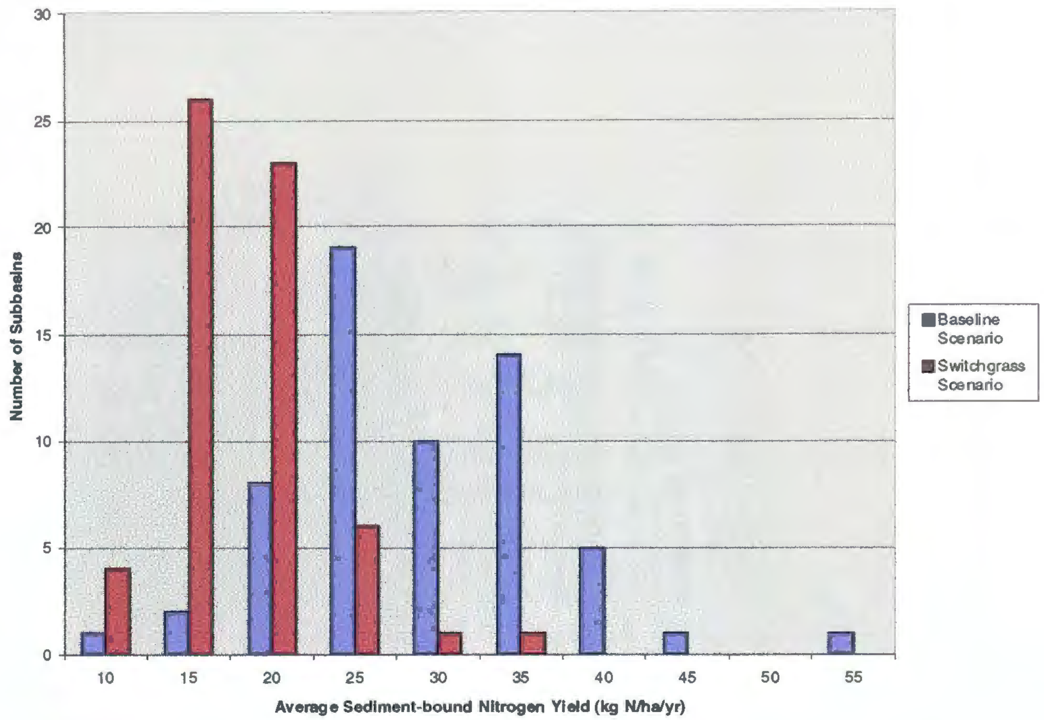

Figure 16 Average Sediment-bound Nitrogen Yield Frequency Distribution

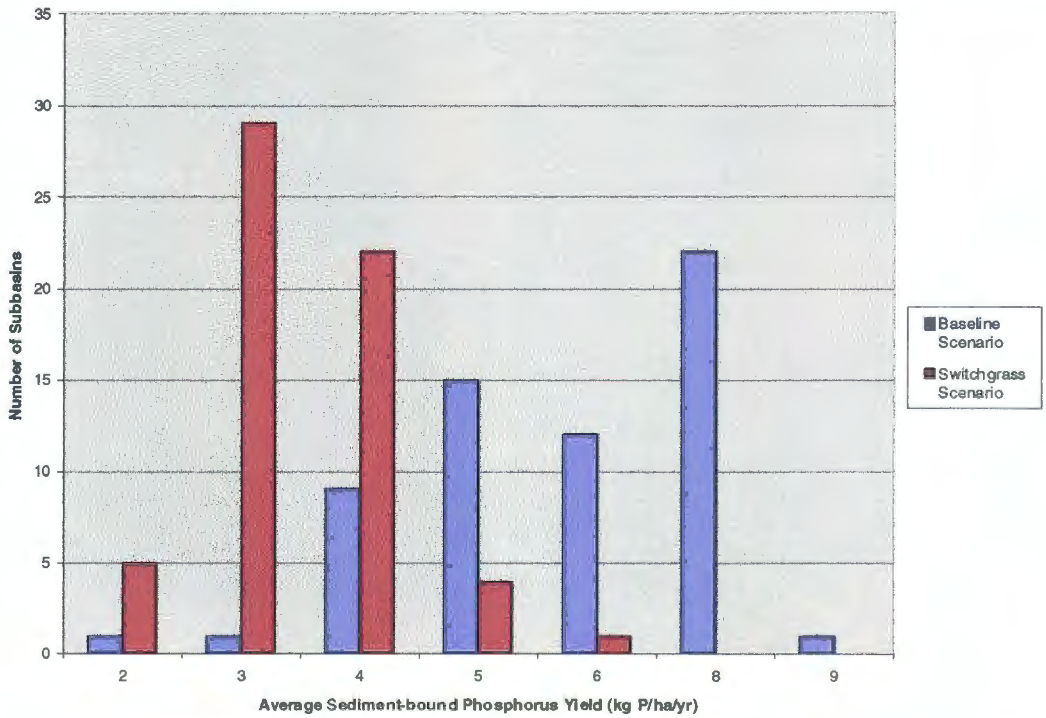

Figure 17 Average Sediment-bound Phosphorus Yield Frequency Distribution

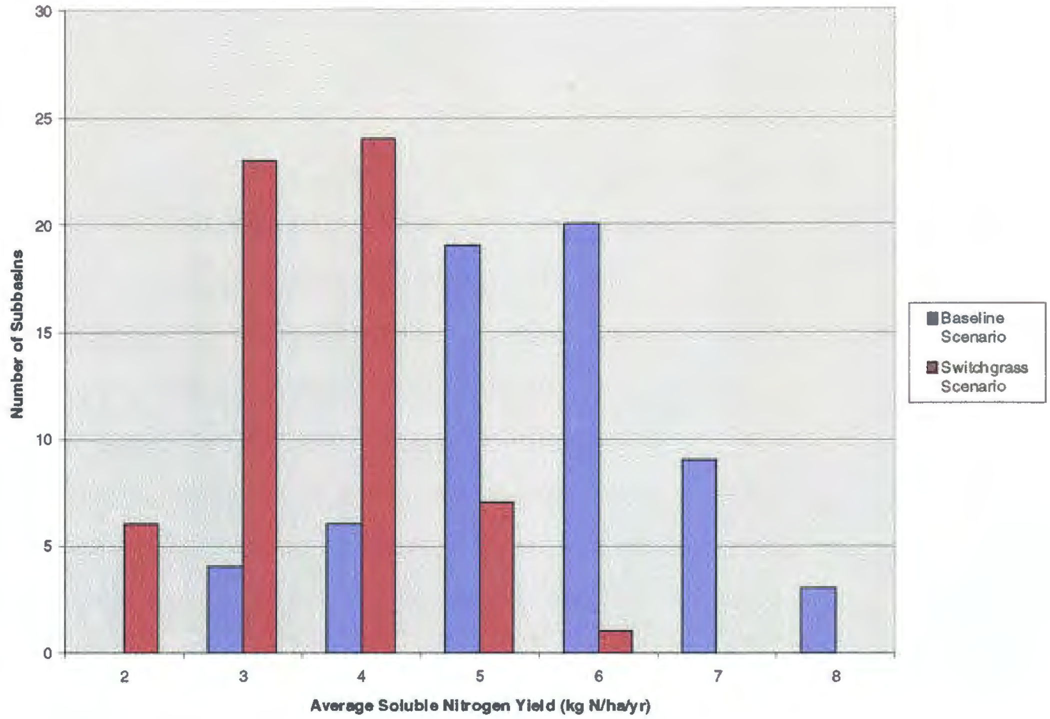

Figure 18 Average Soluble Nitrogen Yield Frequency Distribution

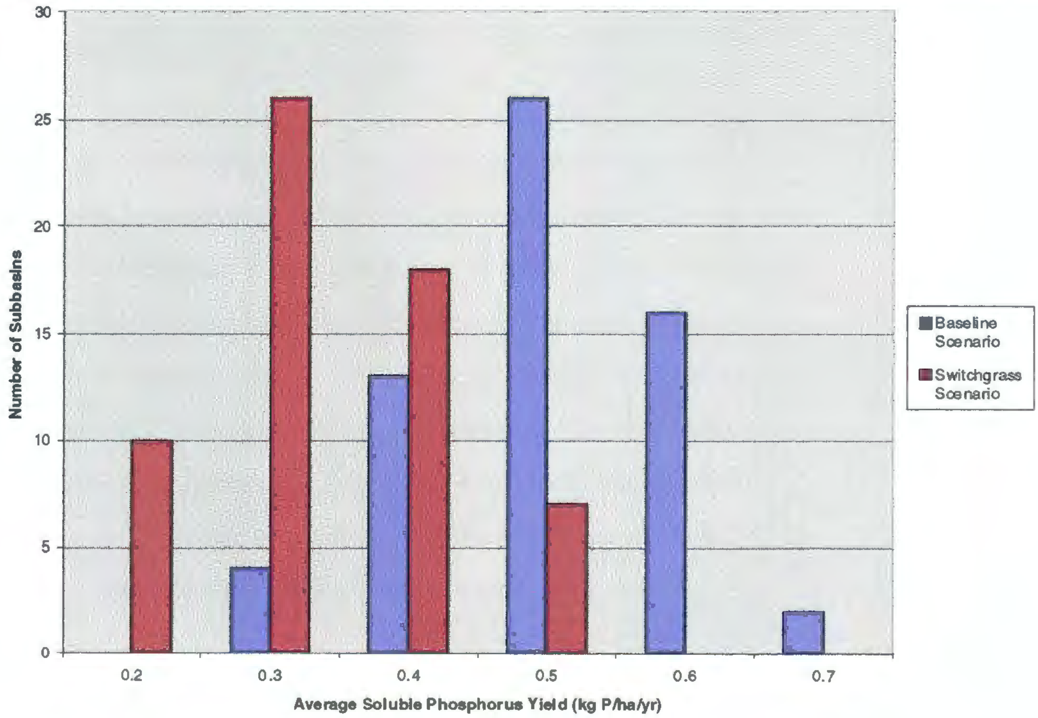

Figure 19 Average Soluble Phosphorus Yield Frequency Distribution

Water Yield

Water yield is the amount of water that eventually flows in the stream and exits the watershed outlet. The water originates from precipitation falling on the watershed or is added to the system through irrigation and is partitioned into several pathways. The three pathways contributing to water yield are: surface runoff, lateral flow of water through the soil profile to the stream, and stream recharge from the shallow aquifer. Surface runoff is the dominant pathway contributing to water yield. Therefore, factors that increase surface runoff will increase water yield. Table 11 shows the effects soil type and land use have on water yield. Water yield increases as percent imperviousness of land use increases (e.g. Forest WYLD < Row Crop WYLD < Urban WYLD). Water yield also tends to increase with decreasing soil water infiltration (e.g. soil hydrologic group B WYLD< soil hydrologic group C WYLD< soil hydrologic group D WYLD). Definitions for the soil hydrologic groups can be found in the SWAT User's Manual Version 99.2 (Neitsch et al., 1999, p. 98). Figures 14 and 15 illustrate the water yield from the 61 subbasins for the baseline and switchgrass scenarios, respectively.

Sediment Yield

Sediment yield is the amount of soil eroded from the subbasin and delivered to the stream reach. SWAT uses the MUSLE equation to estimate this amount of sediment produced. Sediment deposition in streams and water bodies clogs the drainage network, destroys habitat for fish and other invertebrates, and reduces storage capacity and water depth in lakes and reservoirs. Sediment in the water column causes turbidity and reduces light penetration. In addition, sediment is an important parameter for water quality because other potential pollutants are bound to the sediment. Therefore, as the quantity of sediment increases, the potential for other pollutants to be present increases. Table 12 shows the effect soil type and land use has on sediment yield. Agricultural land (row crop) is the dominant source of upland sediment per hectare. Sediment yield tends to increase as water infiltration decreases (e.g. soil hydrologic group B SYLD< soil hydrologic group C SYLD< soil hydrologic group D

SYLD). Figures 16 and 17 show the sediment yield for each of the 61 subbasins for the baseline and switchgrass scenarios, respectively.

Table 11 HRU Water Yield (WYLD) by Soil Type and Land Use Baseline Scenario

Soil	Hyd Grp[1]	Landuse[2]					
		AGRL	FRSD	PAST	URMD	WATR	WETL
		--mm/yr--					
IA004	B	169	136	121			105
IA031	B			136			
IA033	B		134				
IA044	B						99
IA065	B	135	112	81			
KS111	B	178		117	169		
KS146	B	167	89	101	159		
KS175	B	211			190		
MO003	B					0	77
MO007	B	158		87			
IA040	C	273		216	256		
IA043	C				228		
IA053	C		178				
MO009	C			166	222		
MO011	C			187			
MO012	C		182				187
MO018	C	248	181	198			169
MO023	D		293	208			
MO031	D	238	240	203	280		

[1]Soil Hydrologic Group

[2]Landuse Categories for HRUs: AGRL = Agricultural Land, FRSD = Forest, PAST = Pasture, URMD = Urban Land, WATR = Water, and WETL = Wetland

Soil	Hyd Grp[1]	Landuse[2] AGRL	FRSD	PAST	URMD	WATR	WETL
				--Mg/ha/yr--			
IA004	**B**	33.6	0.5	0.5			2.7
IA031	**B**			0.6			
IA033	**B**		0.3				
IA044	**B**						3.1
IA065	**B**	18.1	0.4	0.3			
KS111	**B**	28.5		1.3	0.3		
KS146	**B**	27.5	0.4	0.6	0.3		
KS175	**B**	24.5			0.4		
MO003	**B**					0.0	1.9
MO007	**B**	22.7		0.4			
IA040	**C**	47.6		3.6	0.3		
IA043	**C**				0.4		
IA053	**C**		1.1				
MO009	**C**			1.0	0.4		
MO011	**C**			1.0			
MO012	**C**		1.8				5.5
MO018	**C**	50.7	2.3	2.2			6.2
MO023	**D**		3.9	2.1			
MO031	**D**	51.9	3.3	3.0	0.1		

Table 12 HRU Sediment Yield (SYLD) by Soil Type and Land Use Baseline Scenario

[1]Soil Hydrologic Group

[2]Landuse Categories for HRUs: AGRL = Agricultural Land, FRSD = Forest, PAST = Pasture, URMD = Urban Land, WATR = Water, and WETL = Wetland

Nutrients

Nitrogen and phosphorus are the two nutrients discussed. Both of these nutrients are present as sediment-bound (adsorbed) and as solutes in water. The nutrients dissolved in water will reach Lake Rathbun much more readily than the sediment-bound nutrients.

Phosphorus.

Sediment-bound Phosphorus. Table 13 shows the effect soil type and land use has on sediment-bound (adsorbed) phosphorus yield. The adsorbed phosphorus is predominantly from agricultural (row crop) land. Of course, adsorbed phosphorus is directly related to the quantity of sediment yield. Figures 18 and 19 illustrate the quantity of phosphorus adsorbed to sediment from each subbasin for the baseline and switchgrass scenarios, respectively.

Soluble Phosphorus. Table 14 shows the effect soil type and land use has on soluble phosphorus yield. Soluble phosphorus tends to increase as infiltration rate decreases (e.g. soil hydrologic group B SOLP < soil hydrologic group C SOLP< soil hydrologic group D SOLP). Pasture land use also had the highest soluble phosphorus yield. Figures 20 and 21 illustrate the soluble phosphorus yield from each subbasin for the baseline and switchgrass scenarios, respectively.

Table 13 Sediment Phosphorus Yield (SEDP) by Soil Type and Land Use Baseline Scenario

Soil	Hyd Grp[1]	Landuse[2]					
		AGRL	FRSD	PAST	URMD	WATR	WETL
		--kg/ha/yr--					
IA004	B	30.9	0.7	0.4			3.6
IA031	B			0.5			
IA033	B		0.4				
IA044	B						4.2
IA065	B	21.9	0.6	0.4			
KS111	B	49.6		1.8	1.4		
KS146	B	47.9	0.7	0.7	1.3		
KS175	B	36.1			1.4		
MO003	B					0.0	5.5
MO007	B	41.5		0.4			
IA040	C	60.6		4.0	1.4		
IA043	C				1.4		
IA053	C		1.6				
MO009	C			1.0	1.4		
MO011	C			1.1			
MO012	C		2.8				7.8
MO018	C	26.4	1.8	1.6			4.2
MO023	D		5.6	2.4			
MO031	D	47.5	4.1	4.0	1.2		

[1]Soil Hydrologic Group

[2]Landuse Categories for HRUs: AGRL = Agricultural Land, FRSD = Forest, PAST = Pasture, URMD = Urban Land, WATR = Water, and WETL = Wetland

Table 14 Soluble Phosphorus Yield (SOLP) by Soil Type and Land Use Baseline Scenario

Soil	Hyd Grp[1]	Landuse[2]					
		AGRL	FRSD	PAST	URMD	WATR	WETL
				--kg P/ha/yr--			
IA004	B	0.122	0.063	0.451			0.258
IA031	B			0.511			
IA033	B		0.059				
IA044	B						0.189
IA065	B	0.088	0.040	0.260			
KS111	B	0.132		0.374	0.104		
KS146	B	0.120	0.047	0.368	0.091		
KS175	B	0.149			0.120		
MO003	B					0.000	0.295
MO007	B	0.114		0.333			
IA040	C	0.218		0.789	0.102		
IA043	C				0.124		
IA053	C		0.102				
MO009	C			0.620	0.115		
MO011	C			0.674			
MO012	C		0.129				0.561
MO018	C	0.176	0.113	0.763			0.387
MO023	D		0.207	0.813			
MO031	D	0.177	0.170	0.790	0.056		

[1]Soil Hydrologic Group

[2]Landuse Categories for HRUs: AGRL = Agricultural Land, FRSD = Forest, PAST = Pasture, URMD = Urban Land, WATR = Water, and WETL = Wetland

Nitrogen.

Sediment-bound Nitrogen. Adsorbed nitrogen followed the same trends as adsorbed phosphorus as related to soil type and land use (data not shown). The source of adsorbed nitrogen is predominantly from agricultural (row crop) land and is directly related to the quantity of sediment yield. Figures 22 and 23 illustrate the adsorbed organic nitrogen yield from each subbasin.

Soluble Nitrogen. The effect of soil type and land use on soluble nitrogen is similar to that of soluble phosphorus (data not shown). Soluble nitrogen tends to increase as infiltration rate decreases. Pasture land use also has the highest soluble nitrogen yield. Figures 24 and 25 illustrate the soluble nitrogen yield from each subbasin.

Pesticides—Atrazine

Atrazine is routinely detected in the water of Lake Rathbun and tributaries flowing into the lake. (Kersh and Leonard, 1999) The U.S. Environmental Protection Agency (EPA) maximum contaminant level for atrazine is commonly exceeded in the late spring and summer based upon monitoring data. Figures 26 and 27 illustrate the simulated quantity of atrazine adsorbed to the sediment being transported in the stream for each subbasin for the baseline scenario and the switchgrass scenario, respectively. The "net adsorbed atrazine" is the difference between the quantity of atrazine exiting the subbasin reach and the quantity of atrazine entering the subbasin reach. Negative values indicate subbasins that are sinks for atrazine.

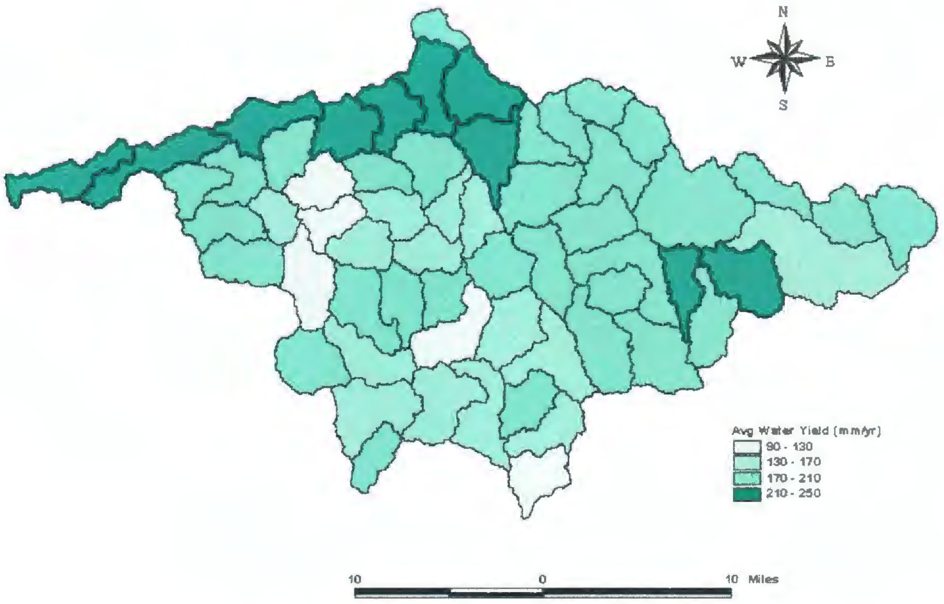

Figure 20 Average Water Yield – Baseline Scenario

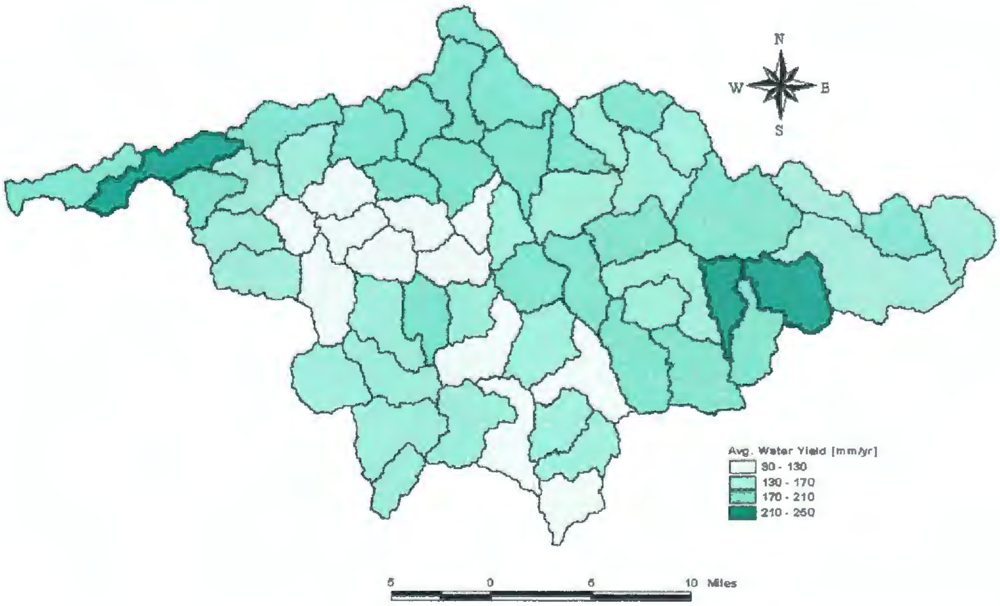

Figure 21 Average Water Yield – Switchgrass Scenario

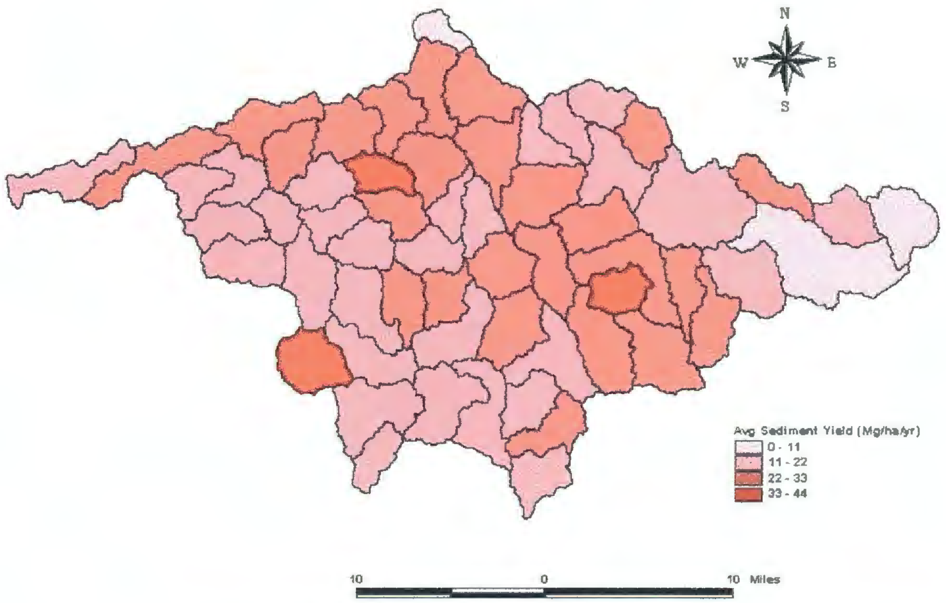

Figure 22 Average Sediment Yield – Baseline Scenario

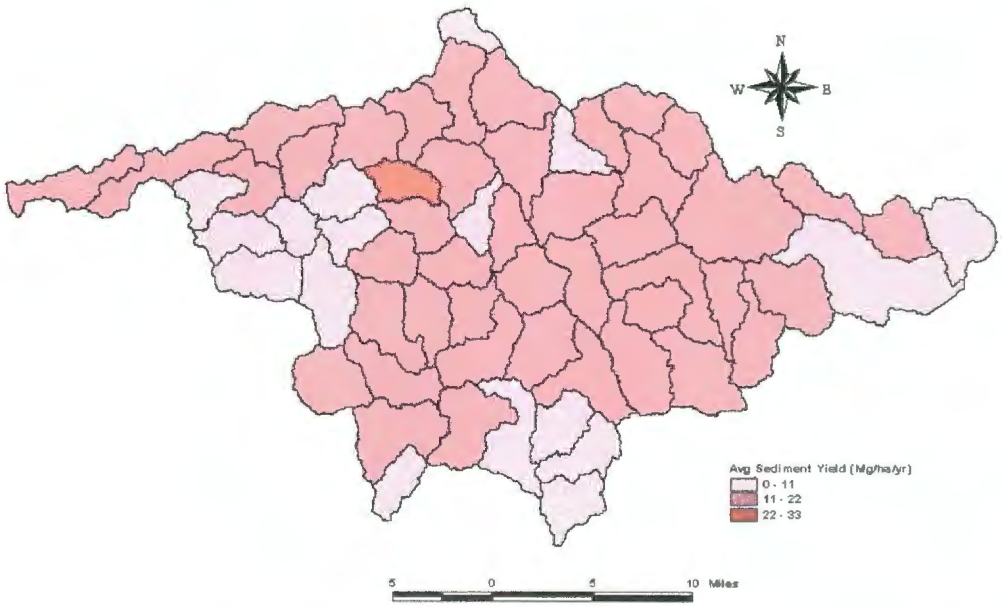

Figure 23 Average Sediment Yield – Switchgrass Scenario

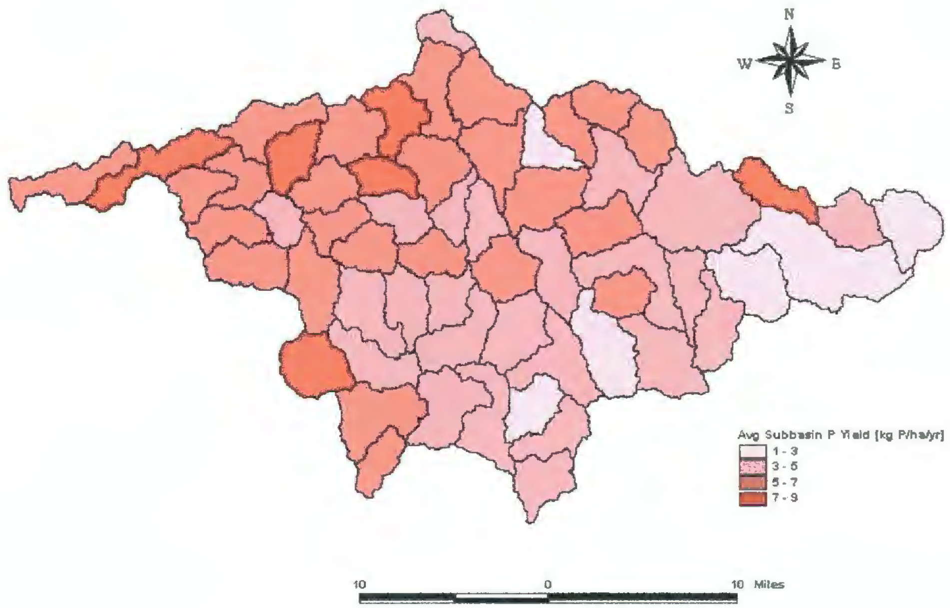

Figure 24 Average Adsorbed Phosphorus Yield – Baseline Scenario

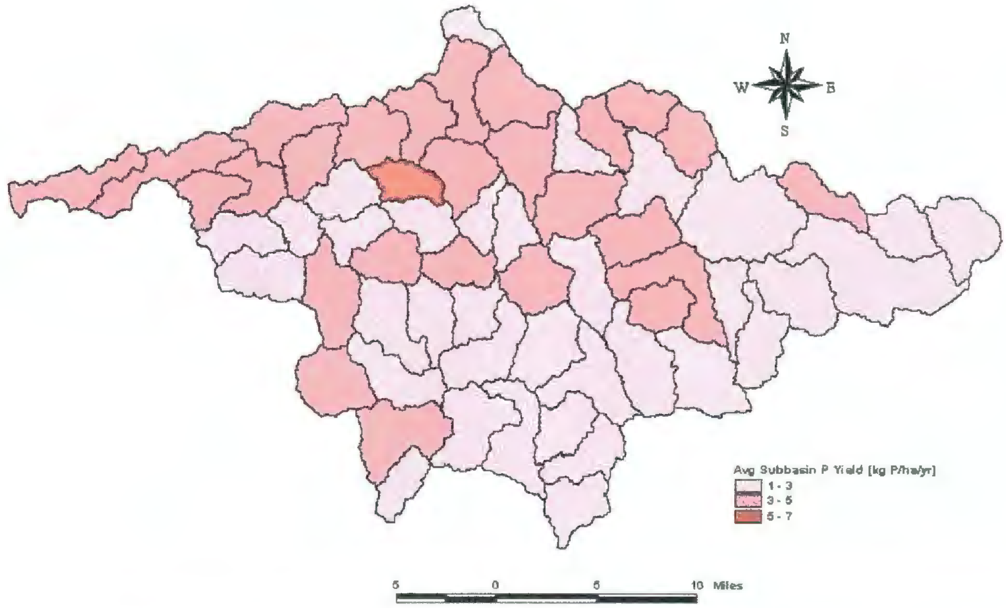

Figure 25 Average Adsorbed Phosphorus Yield – Switchgrass Scenario

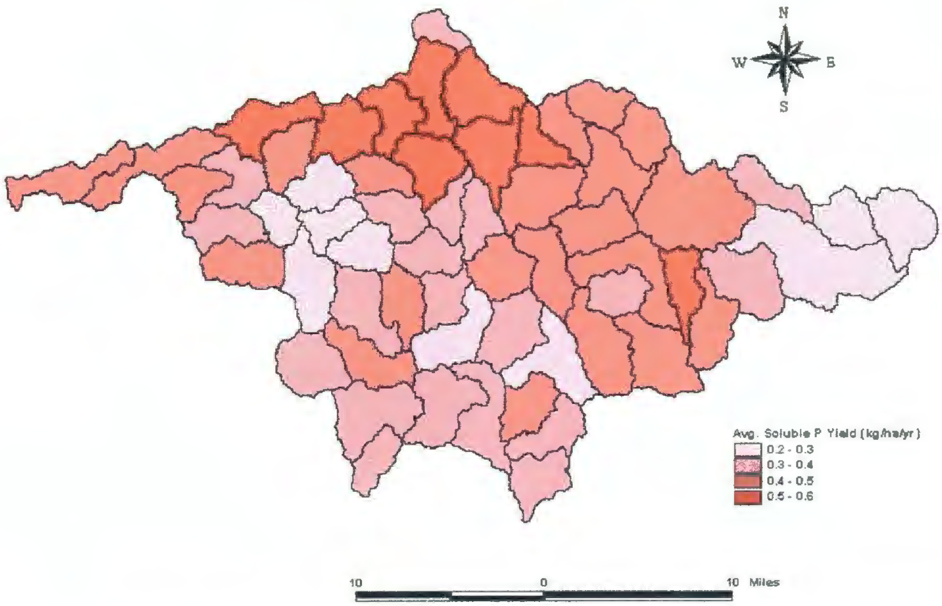

Figure 26 Average Soluble Phosphorus Yield – Baseline Scenario

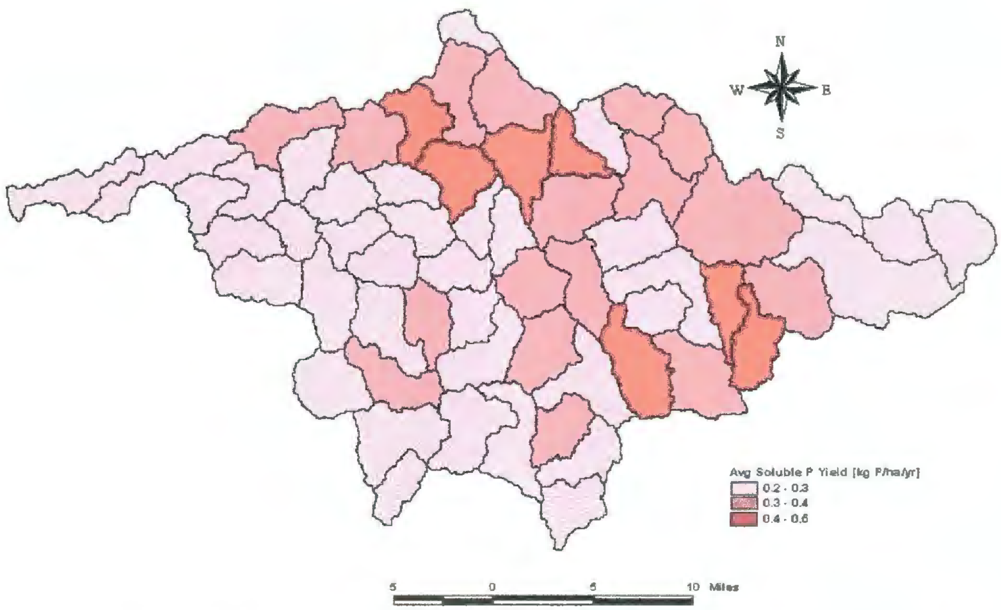

Figure 27 Average Soluble Phosphorus Yield – Switchgrass Scenario

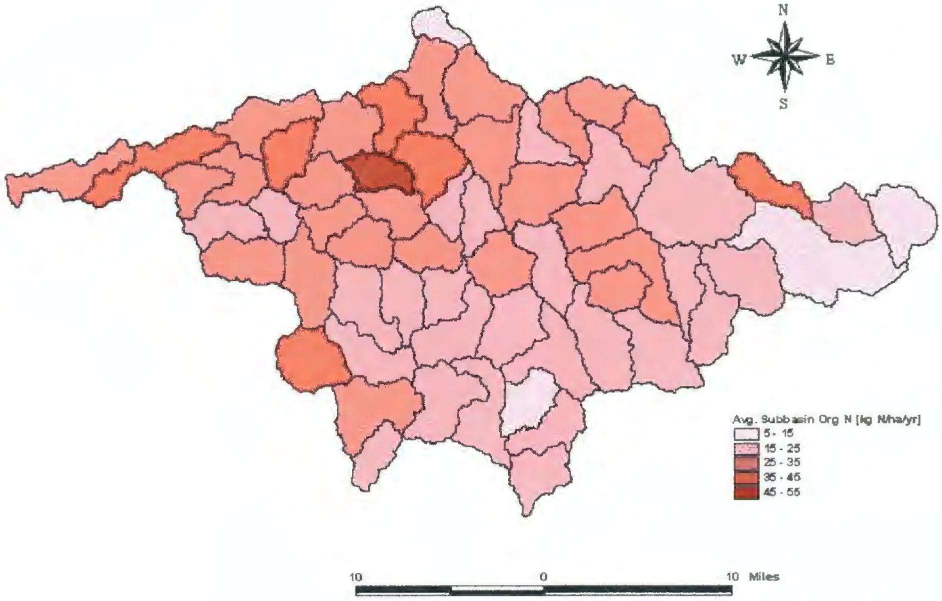

Figure 28 Average Adsorbed Nitrogen Yield – Baseline Scenario

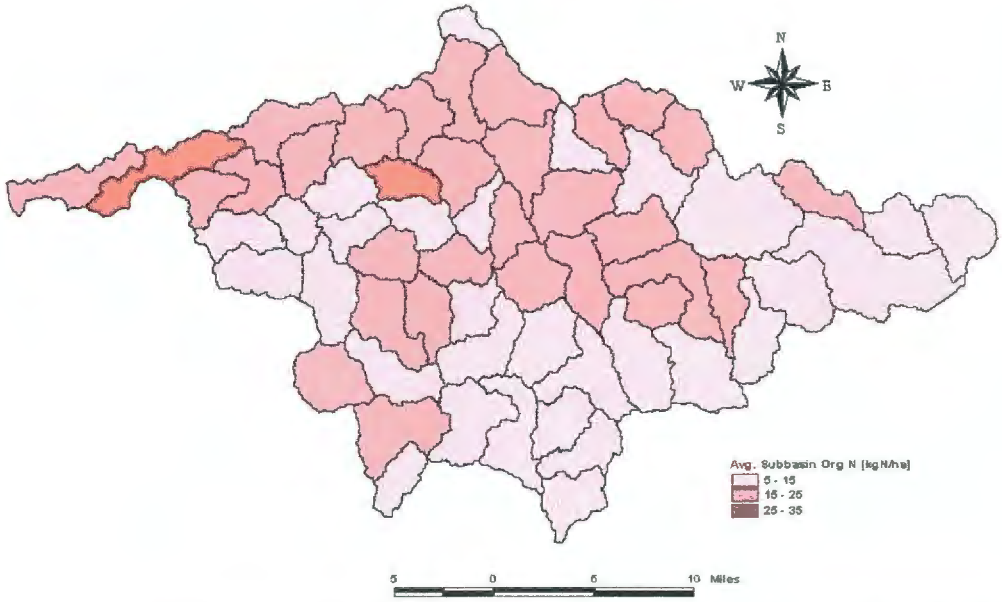

Figure 29 Average Adsorbed Nitrogen Yield – Switchgrass Scenario

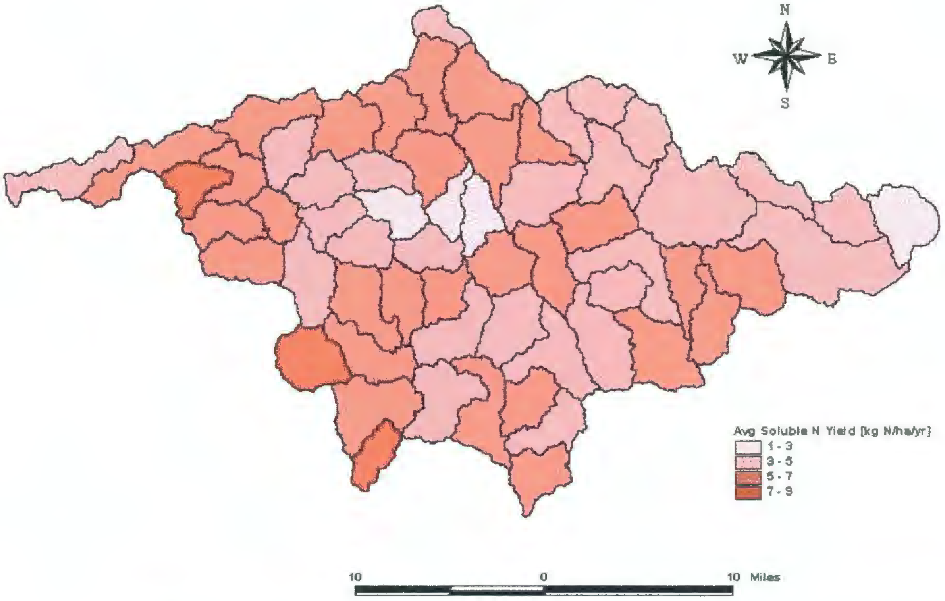

Figure 30 Average Soluble Nitrogen Yield – Baseline Scenario

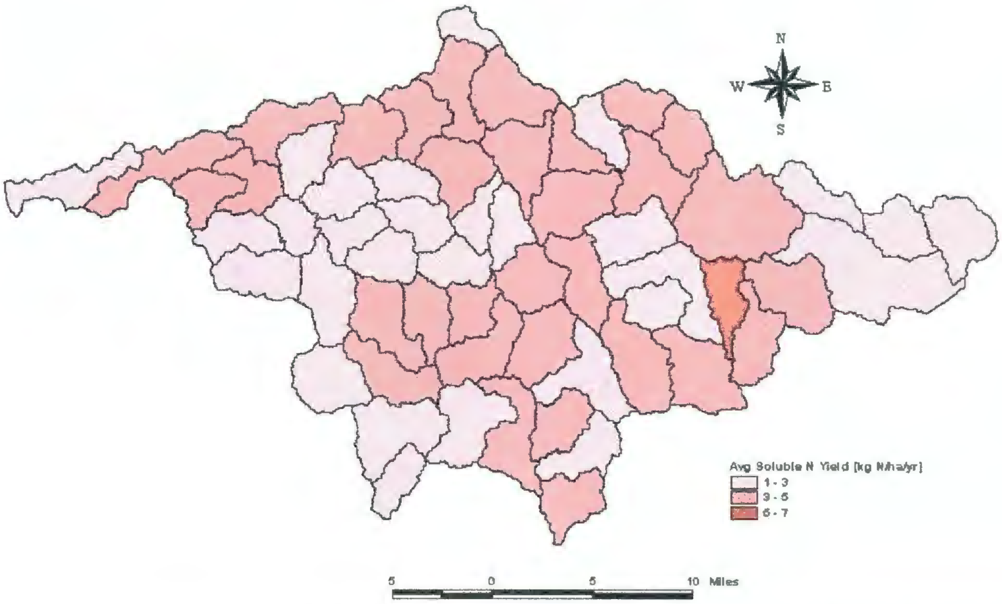

Figure 31 Average Soluble Nitrogen Yield – Switchgrass Scenario

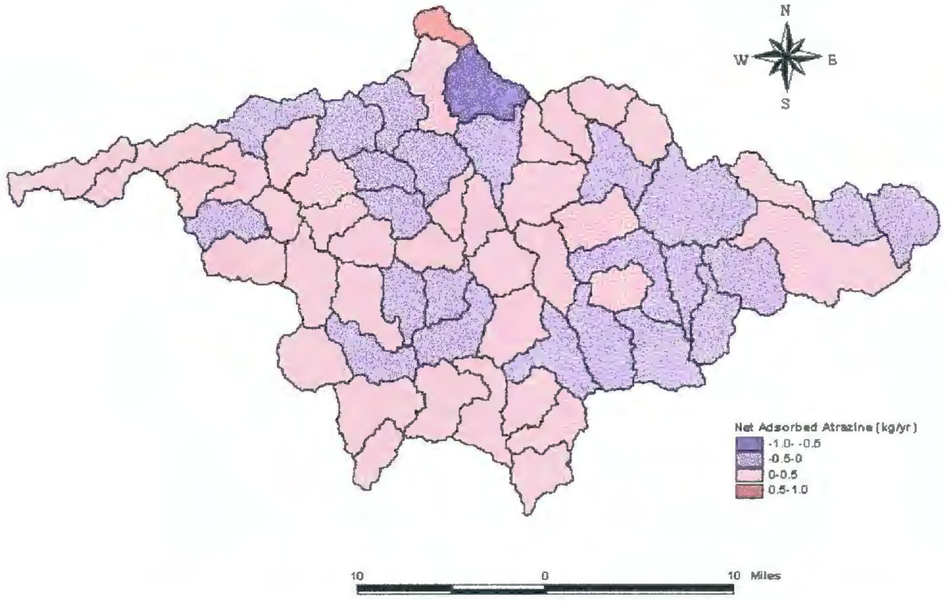

Figure 32 Average Net Adsorbed Atrazine – Baseline Scenario

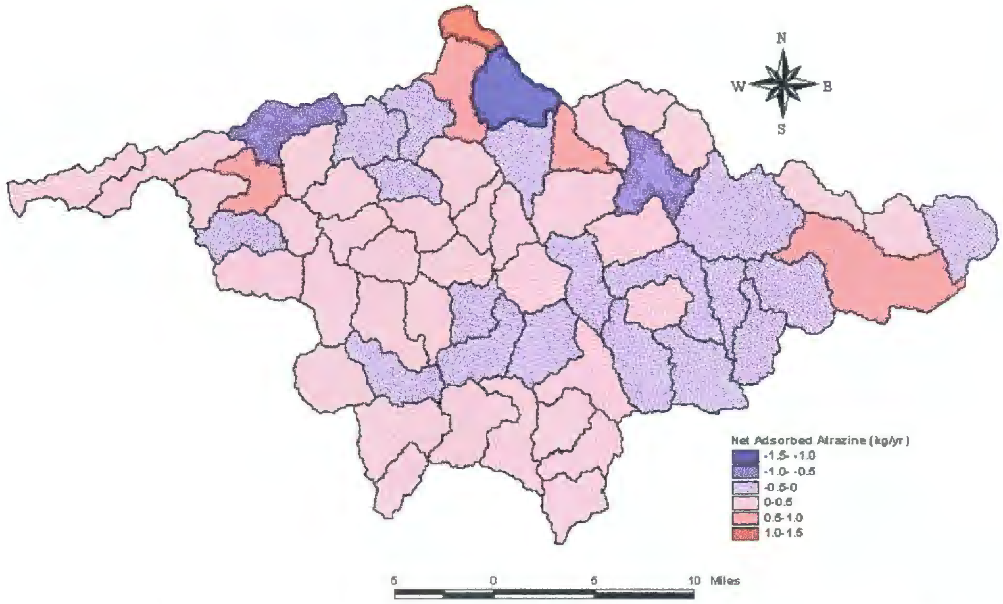

Figure 33 Average Net Adsorbed Atrazine – Switchgrass Scenario

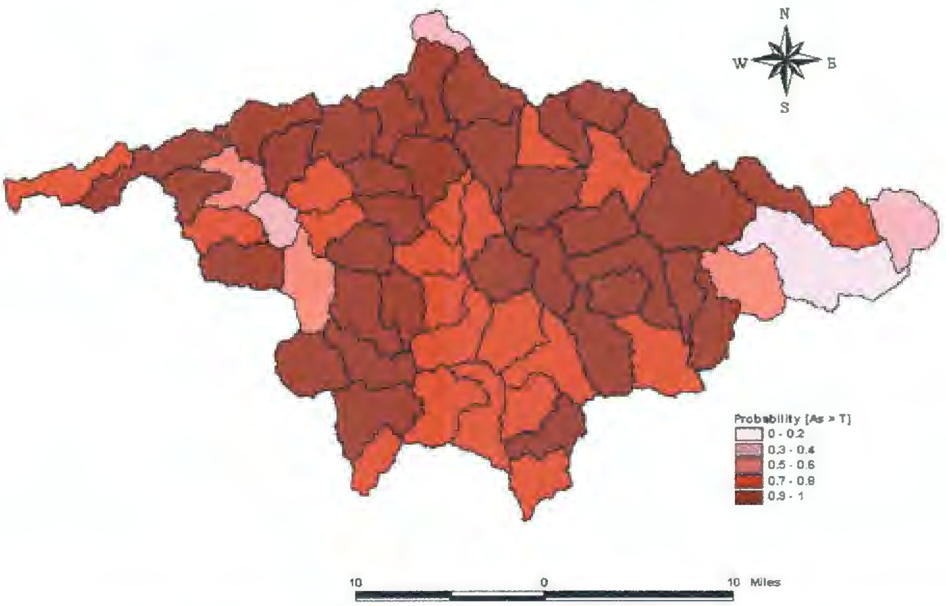

Figure 34 Probability of Subbasins Exceeding T – Baseline Scenario

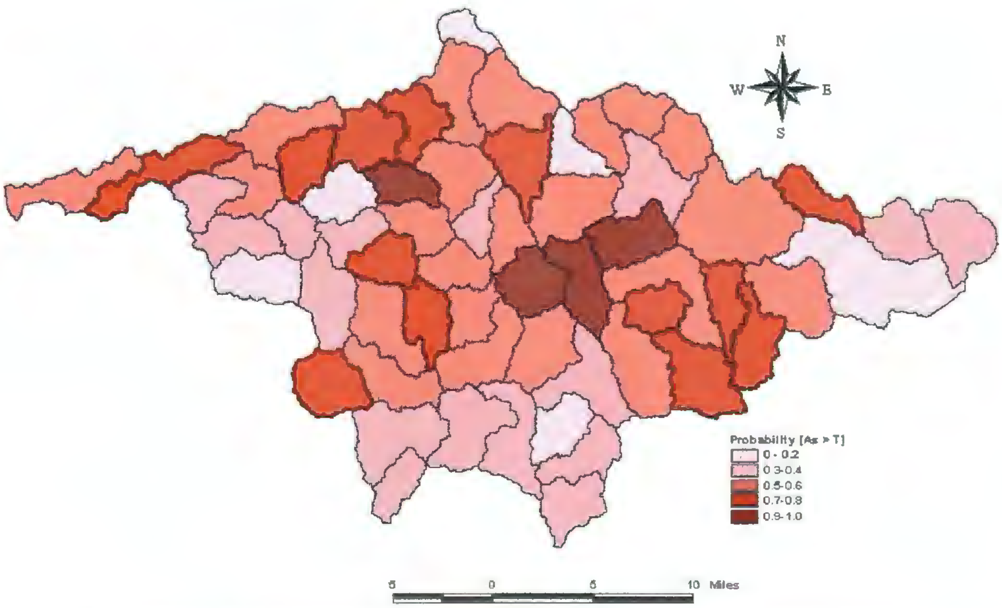

Figure 35 Probability of Subbasins Exceeding T – Switchgrass Scenario

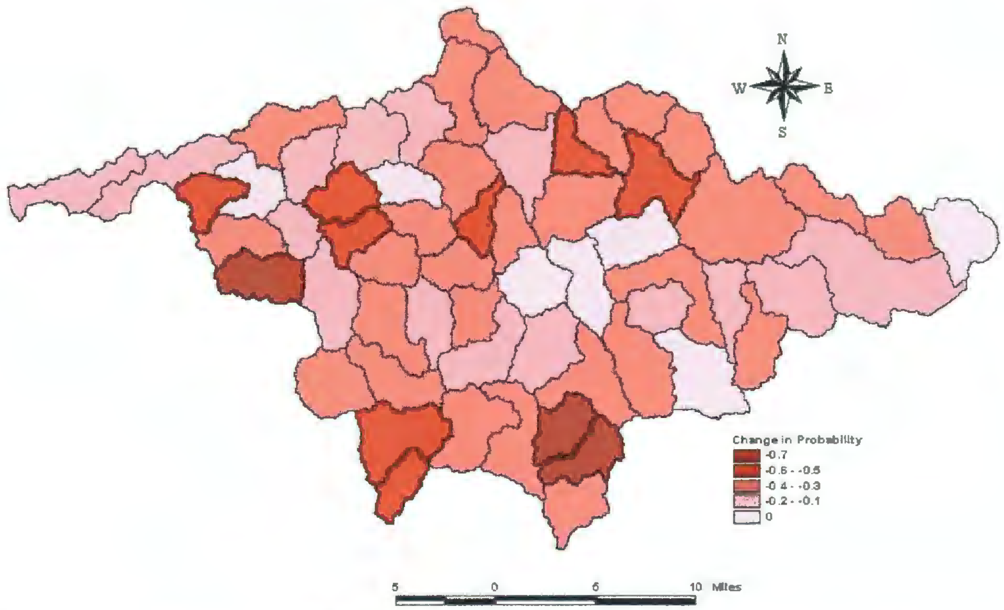

Figure 36 Change in Sediment Yield Probability (Switchgrass Scenario – Baseline Scenario)

Discussion

The water yield is 19% and 17% of average annual precipitation for baseline and switchgrass scenarios, respectively. This is a reasonable value based upon simplified hydrologic cycle partitioning. The switchgrass scenario simulated less runoff compared to baseline conditions. This would be expected due to the perennial nature of the switchgrass. Established switchgrass would be expected to have more surface residue and an established root system improving soil structure to increase water infiltration. However, field experiments conducted in the study area comparing water runoff from corn ground and established switchgrass resulted in more runoff in the switchgrass land use. This discrepancy will need further investigation.

The switchgrass scenario reduced sediment yield 30% relative to the baseline condition by converting 15.3% of the watershed area to switchgrass. Figures 28 and 29 show the probability of individual subbasins exceeding the tolerable soil loss level, “T” for the baseline and switchgrass scenarios, respectively. A value of 11.2 Mg/ha for T was used for these calculations. These graphics summarize the number of years out of ten that the sediment delivery rate using the Modified Universal Soil Loss Equation (MUSLE) exceeded 11.2 Mg/ha. As the probability of exceeding T increases, the probability of excessive sediment being produced that impacts water quality also increases. Figure 30 shows the change in sediment yield probability by subbasin. This value is the difference between the switchgrass scenario sediment yield probability and the baseline scenario sediment yield probability. Negative values indicate that growing switchgrass reduces the frequency that sediment yield exceeds T compared to the baseline scenario. Sediment yield for switchgrass was intermediate between agricultural land and pasture (data not shown). Switchgrass typically produced sediment yields less than the tolerable soil loss level. However, sediment yields of 1.5T – 2T were predicted on some slowly or very slowly permeable soils. Additional soil conservation practices may be needed to prevent excessive erosion from occurring on these soils when growing switchgrass.

Sediment-bound phosphorus is reduced 36% comparing the switchgrass scenario to the baseline scenario. This reduction is primarily due to the reduced sediment yield and the conversion of agricultural land to switchgrass production. This land use conversion reduces the potential loading of phosphorus because phosphorus fertilization is not part of the management practice schedule for growing switchgrass.

Soluble phosphorus yield is reduced 26% comparing the switchgrass scenario to the baseline scenario. Although this reduction could be attributed to the growing of switchgrass, greater reductions would be expected by implementing best management practices to pastureland. Pasture had the highest soluble phosphorus yield in both scenarios. Management practices encouraging a vigorous sod with adequate soil cover and uniform manure distribution will aid in reducing the amount of soluble phosphorus being lost.

Sediment-bound nitrogen is reduced 39% comparing the switchgrass scenario to the baseline scenario. This reduction in sediment-adsorbed nitrogen is due to the reduction of sediment produced by growing switchgrass rather than row crops.

Soluble nitrogen yield is reduced 38% comparing the switchgrass scenario to the baseline scenario. This reduction is attributed primarily to the reduced surface runoff when growing switchgrass compared to growing row crops. However, confounding factors include changing the timing and method of nitrogen fertilization and the fertilizer product used in the scenarios. These factors were not investigated individually to determine their potential impact. A greater reduction response would be expected by implementing best management practices to pastureland. Pasture had the highest soluble nitrogen yield in both scenarios. Management practices encouraging a vigorous sod with adequate soil cover and uniform manure distribution and introducing legumes to replace commercial nitrogen fertilizer will aid in reducing the amount of soluble nitrogen being lost.

The model predicted a decreased quantity of sediment-bound atrazine under the switchgrass scenario relative to the baseline scenario. This is due to the reduced sediment yield of the switchgrass scenario. Sediment-bound atrazine being delivered to Rathbun Lake was reduced approximately 84%. This estimate is based upon the predicted adsorbed atrazine in the stream reach leaving subbasins 17, 22, 32, and 61 and entering subbasin 1 (Figure 13). These subbasins contribute stream flow directly to Rathbun Lake.

The model also predicted a decreased quantity of soluble atrazine for the switchgrass scenario relative to the baseline scenario. The estimated soluble atrazine leaving subbasins 17, 22, 32, and 61 for the switchgrass scenario was 86% less than the baseline scenario.

In summary, SWAT was an appropriate watershed assessment modeling tool to use for this study. It ranked the subbasins as to their relative impact on sediment yield, nutrient loading and pesticide loading. These three output measures are important in agricultural nonpoint source water quality studies.

The purpose of using AVSWAT was to help complete a comprehensive assessment of Rathbun Lake watershed. This assessment has identified specific subbasins (Table 9) that may be causing a disproportionately large share of the water quality problems of Rathbun Lake. Although SWAT generates numeric output values, these results should be used to compare the relative differences between scenarios (i.e. switchgrass and baseline). Based upon the SWAT results in Table 9, knowledge of the SWAT model setup, and general hydrology knowledge, I would classify the following subbasins as "high priority" to receive additional resources to reduce existing sedimentation and/or nutrient enrichment problems: subbasins 9, 36, 37,38, 49 and 53.

As previously discussed, SWAT has been used extensively. However, the ArcView SWAT interface is a recent enhancement and is still under development. Several limitations experienced in this study using the ArcView SWAT interface have been resolved in the interim. Some of these limitations I call computer programming-related and some I call computation-related. One vexing problem related to the computer programming was the entry of the management practice schedule. Although the management practice schedule was easy to enter, it would not save properly. Lines of the management practice schedule would shift out of sequence with one another. This management practice schedule would not read properly and result in a "fatal error" for the simulation. Also, the last land use of the last subbasin in the simulation would not have a management practice schedule written to it in the data entry screen. This was a "non-fatal error" and the project would simulate. Although this problem was extensively investigated, it was never resolved. Another computer programming-related error was the reading of the soils files. SWAT comes complete with STATSGO soils data. The soils properties and interpretations originate from the SCS-Soils-5. Digitized soil lines from the STATSGO map are at a scale of 1:250,000. For this project, it was decided to use the digitized soil maps at a scale of 1:15,840. Finding the correct linkage between the SWAT user soils database and the soils database used in this study was more complex than necessary.

A computation-related limitation of the model was the inability to place ponds or dams any where in the subbasin. In order to simulate a pond, it needed to be located at the outlet of a subbasin. The Rathbun Lake Watershed has thousands of small farm ponds throughout its drainage basin. But for this study, no ponds or other surface impoundments were simulated due to the difficulty of finding appropriate input data and the requirement to add hundreds (or thousands) of subbasins in order to simulate the presence of the ponds. It is assumed that the sediment yields simulated for the baseline conditions are probably high due to this omittance.

One way to improve the overall modeling capability of SWAT and any related interfaces would be to use object-oriented modeling. Bian et al. (1996) used this methodology to develop an Arc/Info SWAT interface.

The ArcView Swat interface should not be used on small watersheds (i.e. watersheds smaller than approximately 800-1000 km^2. Several reasons are proposed to support this statement. First, the ArcView interface calculates an average slope for each subbasin. Second, the lateral flow and shallow aquifer return flow enter the stream within the same subbasin from which it entered the system. Third, the water balance is too crude and inappropriate for small-scale modeling.

Rather than using SWAT as the simulation tool for small watersheds, a better alternative would be to use a field or multi-field scale model to simulate the land and management scenarios. This model output could then be entered into SWAT to simulate the routing through the stream network. This construct has been done on several occasions (Saleh et al., 2000; Keith et al., 2000).

Major Predictions and Conclusions

Major Predictions

- The switchgrass scenario reduced sediment yield 30% relative to the baseline scenario.
- Sediment-bound phosphorus and nitrogen are reduced 36% and 39%, respectively, comparing the switchgrass scenario relative to the baseline scenario.
- Soluble phosphorus and nitrogen are reduced 26% and 38%, respectively, comparing the switchgrass scenario relative to the baseline scenario.
- Sediment-bound atrazine and soluble atrazine quantities delivered to Rathbun Lake are reduced 84% and 86%, respectively, comparing the switchgrass scenario relative to the baseline scenario.
- The predicted reductions in sediment, nutrients, and atrazine are a result of the effects of changing land use and also in the combinations of land use and soils (HRUs) simulated by the model.

Conclusions

1. The SWAT model ranked the 61 subbasins of Rathbun Lake watershed for sediment production, nutrient runoff, and pesticide runoff.
2. Switchgrass for biomass production can be an environmentally friendly practice. However, excessive soil erosion may still occur on slowly or very slowly permeable soils. The use of atrazine as part of the management practice schedule will continue to contribute to the environmental loading of this pesticide.

3. Quantities of sediment-bound pollutants are aligned with sediment yield.
4. A geographic information system used in this study enabled the user to manipulate large quantities of data, visualize data relationships, and develop output maps to convey information to others.

The Soil and Water Assessment Tool (SWAT) is an appropriate tool for this study and other large watershed- or basin-scale analyses. Appropriate field-scale models used in conjunction with SWAT will improve the overall predictive capability of SWAT by providing more detailed, process-oriented input for simulation.

References

Ahrens, W. H. (ed.). 1994. Herbicide handbook. 7^{th} ed. Weed Science Society of America. Champaign, IL.

Arnold, J. G., P. W. Gassman, K. W. King, J. R. Williams, A. Saleh, and U. S. Tim. 1999. Validation of the subsurface tile flow component in the SWAT model. Presented at the 18-22 July 1999, 1999 ASAE/CSAE-SCGR Annual International Meeting, Paper No. 99-2138, ASAE St. Joseph, MI.

Baldwin, O. J. 1937. Flood control studies in the Chariton River basin in Iowa. The Iowa State Planning Board, Des Moines, IA

Beasley, D. B., Huggins, L.F., and Monke, E.J. 1980. ANSWERS: A model for watershed planning. Trans. of the ASAE 23(4): 938-944.

Bian, L.,H. Sun, C. Blodgett, S. Egbert, W. Li, L. Ran, and A. Koussis. 1996. An integrated interface system to couple the SWAT model and Arc/Info. *In:* Third International Conference/Workshop on Integrating GIS and Environmental Modeling, Santa Fe, NM, 21-26 Jan. 1996. Santa Barbra, CA: National Center for Geographic Information and Analysis. Available at: http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/main.html (verified 11 Nov. 2001).

Bingner, R. L., J. Garbrecht, J. G. Arnold, and R. Srinivasan. 1996. Effect of watershed subdivision on simulation of runoff and fine sediment yield. ASAE Paper No. 96-2033. St. Joseph, Mich.: ASAE.

Buland, D., E. Wang, B. Dayton, G. Lawson, and M. DiLuzio. 2001. SSURGO county-level soils data with the SWAT watershed model. [online]. Available at http://waterhome.tamu.edu/NRCSdata/SWAT_SSURGO/ (verified 16 Nov. 2001).

Carlson, R. E. and D. Todey. 2001. Climatological Data Selection Page [online]. Available at: http://www.agron.iastate.edu/climodat/table.html (verified 8 Nov. 2001).

Chariton Basin Planning Board. 1937. General Soil Improvement and Soil Rehabilitation Project. Chariton Basin Planning Board Des Moines (?) Iowa.

Chariton Valley RC&D Project Sponsors. 1972. Chariton valley resource conservation and development project plan. Chariton Valley RC&D Project Sponsors, Centerville, IA

Chow, V. T. 1972. Hydrologic modeling. J. Boston Soc. Civ. Eng. 60 (1): 1-27.

Chow, V. T., D. R. Maidment and L. W. Mays, eds. 1988. Applied Hydrology. New York: McGraw-Hill.

Dillaha, T. A. 2001. ANSWERS 2000 [online]. Available at: http://dillaha.bse.vt.edu/answers/index.htm (verified 18 Nov. 2001).

DiLuzio, M., R. Srinivasan, and J. G. Arnold. 1997. An integrated user interface for SWAT using ArcView and Avenue. Presented at 10-14 Aug. 1997. 1997 ASAE annual international meeting. Paper No. 972235, St. Joseph, MI:ASAE

Donigan, A. S., Jr., and A. S. Patwardhan. 1992. Modeling nutrient loadings from croplands in the Chesapeake Bay Watershed. *In* Proceedings of water resources sessions at Water Forum '92, Baltimore, MD, 2-6 Aug. 1992, p. 817-822.

Fenton, T. E. 2001. Iowa Cooperative Soil Survey [online]. Available at http://icss.agron.iastate.edu/data.htm (verified 5 September 2001).

French-Reneker-Associates, Inc. 1978a. 208 area-wide water quality management plan Chariton Valley Region, Iowa – Part three: the point source plan. French-Reneker-Associates, Inc Fairfield, IA.

French-Reneker-Associates, Inc. 1978b. 208 area-wide water quality management plan Chariton Valley Region, Iowa – Part four: the non-point source plan. French-Reneker-Associates, Inc Fairfield, IA.

Hanson, C. L., K. A. Cumming, D. A. Woolhiser, and C. W. Richardson. 1994. Microcomputer program for daily weather simulation in the contiguous United States. USDA-ARS-114. Washington, D. C.: USDA.

Harmel, R. D., C. W. Richardson, and K. W. King. 2000. Hydrologic response of a small watershed model to generate precipitation. Trans. ASAE 43(6): 1483-1488.

Hauck, L. M. 1999. Enhancement and sensitivity testing of an agricultural nonpoint source watershed assessment model. Ph.D. diss. The Univ. of Texas at Arlington, Arlington.

Iowa Agricultural Statistics Service. 2001. Iowa Agricultural Statistics [Online]. Available at: http://www.nass.usda.gov/ia/ (verified 10 Nov. 2001).

Keith, G., S. Norvell, R. Johes, C. Maguire, E. Osei, A. Saleh, P. Gassman, and J. Rodecap. 2000. CEEOT-LP modeling for the Upper Maquoketa Watershed, Iowa: final report. Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, TX.

Kersh, G. M., and R. A. Leonard. 1999. Rathbun Lake Water Quality Report 1999. Corps of Engineers Kansas City District, Kansas City, MO.

Kirsch, K. J. and A. E. Kirsch. 2001. Using SWAT to predict erosion and phosphorus loads in the Rock River basin, Wisconsin. *In:* Soil Erosion Research for the 21st Century. Proc 3-5 Jan. 2001.

Leonard, R. A., W. G. Knisel, and D. A. Still. 1987. GLEAMS: Groundwater loading effects on agricultural management systems. Trans, ASAE 30(5): 1403-1428.

Loague, K. and R. E. Green. 1991. Statistical and Graphical methods for evaluating solute transport models: Overview and application. *In*: P. J. Wierenga (Guest Editor), Validation of Flow and Transport Models for the Unsaturated Zone. J. Contam. Hydrol., 7: 51-73.

Lockridge, L. D., Soil Survey of Wayne County, Iowa. 1971. U.S. Printing Office, Washington, DC.

Maidment, D. R. 1993. GIS and hydrologic modeling. p. 147-167. *In:* M. F. Goodchild et al. (ed.) Environmental modeling with GIS. Oxford Univ. Press, New York.

Mayhew, J. K. 1969. The physical, chemical, and biological characteristics of the Chariton River prior to impoundment of Rathbun Reservoir. State Conservation Commission, Des Moines, IA

Midwest Regional Climate Center. 2000. Summary statistics from Chariton 1E [online]. Available at http://mcc.sws.uiuc.edu/Summary/Data/131394.txt (posted 3 Jan. 2000, verified 8 Nov. 2001).

Murray, L. W. and C. H. Brown. 1937. General runoff, water retardation, and soil erosion report. Iowa State Planning Board Des Moines, Iowa.

Neitsch, S. L. 2001. Welcome to the official website for SWAT [online]. Available at: http://www.brc.tamus.edu/swat/index.html (posted 27 Sept. 2001; verified 18 Nov. 2001).

Neitsch, S. L., J. G. Arnold, and J. R. Williams. 1999. Soil and Water Assessment Tool User's Manual Version 99.2. Grassland, Soil and Water Research Laboratory Agricultural Research Service. Temple, TX.

Nicks, A. D. 1974. Stochastic generation of the occurrence, pattern, and location of maximum amount of daily rainfall. *In:* Proc. Symposium on Statistical Hydrology, 154-171, Tucson, AZ. USDA Publ. #1275.

Oelmann, D. B. 1984 Soil Survey of Monroe County, Iowa. U.S. Government Printing Office Washington, DC.

Prato, T., H. Shi, R. Rheiw, and M. Brusven. 1989. Soil erosion and nonpoint-source pollution control in an Idaho watershed. J. Soil Water Conserv. 44(4): 323-328.

Prior, J. C. 1991. Landforms of Iowa. University of Iowa Press, Iowa City, Iowa.

Raghuwanshi, N. S. and M. P. Tripathi. 2001. Effect of watershed subdivision on simulated runoff and sediment yield. [Online] *In* Abstracts of technical papers, International SWAT Confernce. Giessen, Germany 12-17 Aug. 2001. Available at: http://www.uni-giessen.de/~gh1175/landeskultur/SWAT.htm (verified 6 Dec. 2001).

Ramanarayanan, T. S., R. Srinivasan, and J. G. Arnold. 1996. Modeling Wister Lake watershed using a GIS-linked basin-scale hydrologic/water quality model. *In:* Third International Conference/Workshop on Integrating GIS and Environmental Modeling, Santa Fe, NM, 21-26 Jan. 1996. Santa Barbra, CA: National Center for Geographic Information and Analysis. Available at: http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/main.html (verified 11 Nov. 2001).

Richardson, C. W., and D. A. Wright. 1984. WGEN: A model for generating daily weather variables. USDA-ARS-8. Washington D. C.: USDA.

Ruhe, R. V. 1969. Quarternary Landforms of Iowa. Iowa State University Press, Ames, IA.

Sadeghi, A. 2001. A SWAT/microbial sub-model for predicting pathogen loadings in surface waters at watershed and basin scales. [Online] *In* Abstracts of technical papers, International SWAT Confernce. Giessen, Germany 12-17 Aug. 2001. Available at: http://www.uni-giessen.de/~gh1175/landeskultur/SWAT.htm (verified 6 Dec. 2001).

Saleh, A., J. G. Arnold, P. W. Gassman, L. M. Hauck, W. D. Rosenthal, J. R. Williams, and A. M. S. McFarland. 2000. appliation of SWAT in the Upper North Bosque River Watershed. Trans. ASAE 43(5): 1077-1087.

Spruill, C. A., S. R. Workman, and J. L. Taraba. 2000. Simulation of daily and monthly stream discharge from small watersheds using the SWAT model. Trans. ASAE 43(6): 1431-1439

Srinivasan, R. and J. G. Arnold. 1994. Integration of a basin-scale water quality model with GIS. Water Resources Bulletin. 30(3): 453-462.

Srinivasan , R., J.G. Arnold, R. S. Muttiah and P.T. Dyke. 1995. Plant and hydrological simulation for the conterminous U.S. using SWAT and GIS. Hydrological Science and Technology: 1995 (10) 1-4. pp 160-168. American Institute of Hydrology.

State Historical Company. 1881. History of Lucas County Iowa. State Historical Company Des Moines.

Tim, U. S. 1995. Emerging Technologies for Hydrologic and Water Quality Modeling Research, Trans. ASAE, 39(2): 465-476.

Tim, U. S. and R. Jolly. 1994. Evaluating agricultural nonpoint-source pollution using integrated geographic information systems and hydrologic/water quality model. J. Environ. Qual. 23: 25-35.

United States Army Corps of Engineers. 2001. Rathbun Lake Homepage [Online]. Available at: http://www.nwk.usace.army.mil/rathbun/rathbun_home.htm (verified 7 Nov. 2001).

United States Department of Agriculture Natural Resources Conservation Service Soil Survey Division. 2000. National SSURGO Database [online]. Available at: http://www.ftw.nrcs.usda.gov/ssur_data.html (posted 13 July 2000, verified 19 Nov. 2001).

United States Environmental Protection Agency Office of Science and Technology. 2001. BASINS: Better assessment science integrating point and nonpoint sources [online]. Available at: http://www.epa.gov/OST/BASINS/ (posted 16 Oct 2001; verified 18 Nov. 2001).

United States Environmental Protection Agency Office of Wetlands, Oceans, and Watersheds. 2000. Compendium of tools for watershed assessment and total maximum daily loads (TMDL) development [online]. (last revised 15 Apr. 2000; verified 18 Nov. 2001

United States Geological Survey. 2000. Land Cover Characterization Program [Online]. Available at http://mac.usgs.gov/mac/isb/pubs/factsheets/fs10800.html#products (verified 31 Aug. 2001).

Vache, K. B., J. E. Eilers, M. Santelmann. *In press.* Water quality modeling of alternative agricultural scenarios in the U. S. Corn Belt. JAWRA.

Western Historical Company. 1878. The history of Appanoose County Iowa. The Western Historical Company, Chicago.

Williams, J. R. 1975. Sediment-yield prediction with the universal equation using runoff energy factor. P.244-252. *In* Present and prospective technology for predicting sediment yield and sources: Proceedings of the sediment-yield workshop, USDA Sedimentation Lab, Oxford, MS, November 28-30, 1972. ARS-S-40.

Williams, J. R., C. A. Jones, P. T. Dyke. 1984. A modeling approach to determining the relationship between erosion and soil productivity. Trans. ASAE 27(1): 129-144.

Wischmeier, W. H. and D. D. Smith. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. Agricultural Handbook 282. USDA-ARS.

Wischmeier, W. H. and D. D. Smith. 1978. Predicting rainfall erosion losses: a guide to conservation planning. Agricultural Handbook 537. U. S. Gov. Print. Office, Washington, D. C.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1987. AGNPS, Agricultural Non-Point-Source Pollution Model: A watershed analysis tool. Conservation Research Report 35. USDA Agricultural Research Service. Washington, D.C.

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